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USING PARAMETRIC COST MODELS TO ESTIMATE ENGINEERING AND INSTALLATION COSTS OF SELECTED ELECTRONIC COMMUNICATIONS SYSTEMS

THESIS

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THESIS

Presented to the Faculty of the Graduate School of

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Requirements for the Degree of

Master of Science in Cost Analysis

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John Bosworth

Ron Wiechmann

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Acronyms

AAD- Advanced Academic Degree
ADS- Automatic Data System
AF- Air Force
AFB- Air Force Base
AFCC- Air Force Communications Command
AFIT- Air Force Institute of Technology
ANG- Air National Guard
ASC- AUTODIN Switching Center
ATCALS- Air Traffic Control and Landing System
AUTODIN- Automatic Digital Network
AUTOSEVOCOM- Automatic Secure Voice Network
AWS- Air Weather Service
BAN- Base Area Network
BBS- Bulletin Board System
BCTF- Base Central Test Facility
BISS- Base Intrusion Security Systems
CAN- Campus Area Network
CATV- Community Antenna Television
CCTV- Closed Circuit Television
CE- Concept Exploration
CER- Cost Estimating Relationship
CSC- Communications Systems Center
DBOF- Defense Business Operations Fund
DDN- Defense Data Network
DEM/VAL- Demonstration and Validation
DISNET- DDN Integrated Secure Network
DMRD- Defense Management Review Directive
DoD- Department of Defense
E&I- Engineering and Installation
EIC- Engineering Installation Center
EID- Engineering Installation Division
EIS- Electronics Installation Squadron
EMD- Engineering and Manufacturing Development
FAA- Federal Aviation Administration
FM- Financial Management
GDP- Gross Domestic Product
GEEIA- Ground Electronics Engineering Installation Agency
HQ- Headquarters
I&M- Installation and Maintenance
ISDN- Integrated Service Digital Network
ITA- Information Transfer Architecture
JSIIDS- Joint Service Interior Intrusion Detection Systems
LAN- Local Area Network

LEAD- Low-Cost Encryption and Authentication Device
LMR- Land Mobile Radio
LSBF- Least Squares Best Fit
MCP- Military Construction Program
MSE- Mean Square Error
MSR- Mean Square Regression
NMS- Network Management System
NWS- National Weather Service
O&M- Operations and Maintenance
OSD- Office of Secretary of Defense
PBX- Private Branch Exchange
PCE- Professional Continuing Education
POM- Program Objective Memorandum
PPBS- Planning, Programming, and Budgeting System
PPI- Producer Price Index
QA- Quality Assurance
SAS- Statistical Analysis System
SCEA- Society of Cost Estimators and Analysts
SSE- Sum of Squares Error
SSR- Sum of Squares Regression
SSTO- Sum of Squares Total
STEM- Systems Telecommunications Engineering Managers
TCC- Telecommunication Center
TDY- Temporary Duty Assignment
UCR- Unit Cost Resource
VIF- Variance Inflation Factor
VTC- Video Teleconferencing
WAN- Wide Area Network
WBS- Work Breakdown Structure

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Abstract

This study developed a set of cost driver definitions for use by the Communications Systems Center (CSC), headquartered at Tinker AFB, Oklahoma. CSC is responsible for the engineering and installation of a dozen types of ground-based electronic communication and navigation systems, ranging from mobile radio systems to base telephone switches and air traffic control systems. Under changes brought about by the implementation of the Defense Business Operating Fund (DBOF), the Communications System Center is searching out new customers and new cost estimating methodologies to improve customer service.

The definitions were used to gather historical data of equipment, engineering, and installation costs of Local Area Networks, Information Transfer Architecture (ITA), and Network Management Systems. From the gathered data, the researchers were able to construct a Cost Estimating Relationship for predicting the costs of an ITA project that are passed through to CSC customers. This ITA model will be used by CSC to estimate pass through costs early in the bidding process.

USING PARAMETRIC COST MODELS TO ESTIMATE ENGINEERING AND INSTALLATION COSTS OF SELECTED ELECTRONIC COMMUNICATIONS SYSTEMS

I. Introduction

General Issue

The primary mission of the Communications Systems Center at Tinker AFB, Oklahoma is to provide world-wide communication system engineering and installation services to Department of Defense and other governmental agencies on a fee-for-service basis. As part of this mission, the Communication Systems Center (CSC) must provide potential customers with accurate cost estimates of proposed projects. The current method of making cost estimates is often inaccurate, resulting in cost estimates that are unrealistic when compared to final project costs.

As a provider of goods and services operating in the new fee-for-services environment, CSC must compete with other governmental as well as commercial providers of like services. To remain competitive under these circumstances, CSC must strive to provide high quality engineering and installation services at a low cost and in a timely manner. While customer satisfaction is intimately related to those factors, it can be impaired when early cost estimates are not realistic. The result of estimates that are too low can be overspent budgets and last-minute fund re-allocations that create havoc for customers. Estimates that are too high cause other worthy projects to go un-funded and can result in fiscal year-end fallout and last minute spending decisions in order to minimize future year budget decreases.

The initial cost estimates provided by CSC to customers are used for several purposes. First, they provide the customer a source of comparison when competing with other projects for the limited resources that are available. Second, cost estimates are used by customers to compare proposed bids on the same project. Finally, the estimates serve as baseline figures for out-year budgeting as requirements are entered in the Program Objective Memorandum (POM) via the Planning, Programming and Budgeting System (PPBS).

Background

When the Air Force became a separate branch of service in 1947, the Engineering and Installation (E&I) mission was performed by scattered Installation and Maintenance (I&M)

units that were located both in the US and abroad. In 1958, Chief of Staff General Curtis LeMay created the Ground Electronics Engineering Installation Agency (GEEIA). GEEIA was the first step in a unified EI organization and was assigned as part of the Air Materiel Command. In 1970, GEEIA was absorbed into the Air Force Communications Service, which later became the Air Force Communications Command (AFCC) [30:1].

As part of an internal reorganization in the early 1980's, AFCC re-established centralized control of the EI mission by creating the Engineering Installation Center (EIC) at Tinker AFB on 1 June 1981. The center was renamed the Engineering Installation Division (EID) on 1 March 1985, a name more in keeping with the center's role as a headquarters with subordinate units. In 1987, AFCC gave EID the additional responsibility for procurement of off-the-shelf comm-electronics equipment (such as LAN components and secure telephone switches), and providing life cycle support services for EID customers [30:1,2].

Further restructuring began in February of 1991 and resulted in the merging of AFCC's Command and Control Systems Organization into EID, implementation of fee-for-service, and several other initiatives that had been in the planning stages. On 1 October, 1991, EID became the

Communications Systems Center, Headquartered at Tinker AFB, Oklahoma [30:2,3].

Fee-for-Service

The idea of fee-for-service came out of an attempt to promote efficiency in the operation of Air Force service organizations. Fee-for-service requires service organizations to charge customers based on the level of service provided, as a way of recouping cost. The theory is that service organizations will be forced to compete for funding with commercial businesses and other DoD service organizations, with only the most efficient surviving. Over time, lower-cost, higher-quality units will result from the increased level of competition.

Problem Statement

The Communications Systems Center currently uses a man-hours approach to estimate Engineering and Installation costs. Since implementing fee-for-service, the estimates have not accurately reflected actual costs and have caused budgeting problems for the customers. Because of the recent change to a fee-for-service funding environment, the need for accurate historical data for cost estimating is also new. This means that collection of historical cost data will require a lot of effort in order to build a parametric model for estimating engineering and installation costs. In most cases, possible cost drivers have not even been defined for collection so a major part of the effort will go toward just defining plausible cost drivers.

Research Objectives

The ultimate objective of this research track is to develop a complete series of Cost Estimating Relationships (CERs) to model costs for several categories of CSC projects. The objective of this thesis is begin that effort by determining what plausible cost driver categories exist for a reduced set of commodities that are installed by the CSC. For those commodities that have enough historical data available, an attempt will be made to develop a parametric cost estimating equation to replace or supplement the current estimating approach. The results of this research will provide CSC with a set of hypothesized cost drivers for each of this set of commodities that are installed on an ongoing basis. Collection of the necessary data over the next several years will allow statistical analysis at some future date with the goal of developing valid cost estimating relationships for all of the CSC commodities. For those commodities with historical data available now, a cost estimating relationship will be developed and provided to CSC.

Investigative Questions

To fulfill the research objectives, the following questions must be answered:

1. What commodities installed by CSC units are in need of better estimating methods?
2. What plausible cost drivers can be identified for each commodity in question, for both immediate and continuing data collection?
3. What historical cost and engineering data is available right now for each commodity in question?
4. For commodities with data available, what statistically valid cost estimating relationships exist, based on historical costs and the hypothesized cost drivers?

Scope/Limitations

Parametric cost model relationships are based upon logical relationships of cost drivers and system costs. Those relationships require a methodical model building process and statistical analysis tools available on capable computers to best fit the historical costs of fielded systems. In the case of the Communications Systems Center, much of the historical data was not collected in a manner that is conducive to ready analysis. The original intention of the research was to estimate the cost of approximately a dozen different types of systems using perhaps 30 cost estimating relationships. Due to the difficulty in obtaining data, the scope of the effort was narrowed to system types. The amount of time and effort required to develop the data collection effort became a major limitation to the research effort.

From the beginning, this effort was aimed at investigating whether a parametric cost model could provide a quick, simple, and accurate method for estimating engineering and installation costs for the type of projects managed by CSC. The focus of a parametric model is very early in the program definition, often before all of the requirements of the system are known. As the program moves through development, other costing approaches may be used to refine the estimate. Examples of other approaches that might be used include a detailed engineering cost buildup or estimating based on the cost of an analogous system. Both of those methods could involve hundreds of hours of preparation when the goal is simply a quick and reasonable estimate.

Summary

The remainder of this thesis is divided into four chapters. Chapter II discusses the implications of the Defense Business Operations Fund (DBOF) on Unit Cost Resourcing (UCR) and Fee-for-Service pricing as well as reviewing the cost estimating methods now in use by CSC. Chapter III presents the methodology used to develop the models in question. The analysis and development of the parametric models is covered in Chapter IV. Chapter V provides a summary of the research along with recommendations for follow-up efforts.

II. Literature Review

Chapter Overview

This literature review is divided into four sections. Section one discusses the on-going move towards a more "business-oriented" attitude in reducing the cost of services provided by support units within the Department of Defense (DoD). The first section includes a review of the Defense Business Operations Fund (DBOF), Unit Cost Resourcing (UCR), and the current reimbursement method in use by the Communications Systems Center (CSC). Section two presents on the various commodities CSC engineers and installs. Section three examines the various methodologies that can be used to make cost estimates. The fourth and final section reviews previous research conducted in the area of parametric cost modeling for communications systems, as well as current cost estimating practices in use at Communications Systems Center (CSC).

Changes to Air Force Funding System

Background. In 1986 the Air Force personnel strength reached a post Vietnam-era high with 608,199 active duty personnel(35:28). By 1994 the total strength is programmed to number only 425,700 (35:28). At the same time the budget has been reduced considerably as well. The Air Force budget for Fiscal Year (FY) '85 expressed in constant 1994 dollars was approximately $129.9 Billion (B) while the budget for FY '94 is down to $73.7B (35:32). While huge cuts have been made to personnel and budgets, more needs to be done to bring support costs in line with other cuts already made. It is projected that by 1997 the budget will have declined by 40% and active-duty military end strength by 30% from 1985 levels, while infrastructure will have only declined by 15% (26:11, 27).

With all of the recent cuts in the military it is clear that just cutting the budget and personnel will not solve all of the funding problems. In August 1989 the Office of the Secretary of Defense (OSD) initiated the cost per output program which was followed by the issuance of the Unit Cost Resourcing (UCR) Guidance in 1990 (27). Defense Management Review Directive (DMRD) 971 established the Defense Business Operations Fund (DBOF) as a revolving fund on 1 October 1991.

The purpose of Unit Cost Resourcing (UCR) and DBOF is to give managers a better means to identify costs and then manage their resources in a more effective manner. What follows is a brief history of revolving funds as well as some background information on DBOF and UCR.

Revolving Funds. A revolving fund is defined by DoD 7420.13-R, Stock Fund Operations as:

> A funding concept that allows the use of funds received from sale of items or services to customers to acquire assets for resale to customers. For example, a stock fund sells parts to a customer and uses the funds collected from the customer to pay for parts acquired to restock its inventory. (15:48)

The revolving fund identifies to the supplier what items are needed by the forces and also lets the customer know the cost incurred for the use of the services or products.

The first use of revolving funds in the military can be traced all the way back to the Navy's use of stock funds for various activities beginning in 1878 (23:16 and 15:46). More recently, the National Security Act of 1947 authorizes the Secretary of Defense to establish revolving funds as a means to more effectively control the cost of work performed by DoD support activities.

In the 1950's and 1960's revolving funds evolved into two categories: stock funds and industrial funds. The stock funds dealt with procuring material in volume from commercial sources and holding it in inventory. Items would be sold to the military service customer in order to maintain weapon system readiness. Industrial funds on the other hand served activities that provided industrial and commercial goods or services such as depot maintenance, transportation, and research and development. Both were financed primarily by reimbursement from customer's appropriated funds (23:16).

A weakness of the old budget system is that units receive funds based on their spending history. Whatever you received last year, you will get next year plus an inflation factor. Another problem was the emphasis on spending all of the funds received (27). If funds were left over at the end of the year, less funding would be made available in future years since it had not been needed in the past. Also, in many cases the true costs of operating a unit were hidden in centralized pots of money. Many items were handed out as "free issue" from supply (27).

The new emphasis is to determine unit cost per output. Support units will sell their products or services and not simply "give them away." The budget, and subsequently funding, will be based on a unit cost target and not history (27). The ultimate goal is to manage support costs by total costs incurred.

Defense Business Operations Fund (DBOF). DBOF is a large revolving fund "umbrella" created by DoD on 1 October 1991 for the purpose of achieving the following Defense Management Review initiatives:

1. consolidate like functions,
2. increase cost visibility, and
3. realize significant monetary savings through better business practices. (12:1)

Until the development of DBOF, the support level provided by a unit was determined more by the level of funding and not necessarily by the level of need. This should change under DBOF because the customer will be the main determinant of support levels. Since the customer "buys" support activities, they receive the funds and in turn pay the support units for services provided.

DBOF is intended to eliminate the system of the past where goods and services were issued at no cost to the user and thus often wasted. In addition, units have the option of choosing between a government or private vendor to receive their support goods. By making this option available to operational units, DoD support units are forced to become more competitive and efficient in the way they conduct their business.

Under DBOF (full cost transfer pricing) or reimbursement scenarios (direct cost transfers excluding military personnel and depreciation), funding for support services is provided directly to the operating forces (21:15). The main difference between DBOF and reimbursements is flexibility. Under the current system appropriated money can not be transferred from one category to another. So, if a unit has extra Military Construction (3300) money and is short of Operations and Maintenance (3400) money, the funds can not be transferred. However, under the DBOF system funds do not carry a specific designator, allowing the individual units the autonomy to determine how to best use their allotted funds.

Currently, most Air Force operations are financed through direct appropriations from the general fund of the United States Treasury (22:44). Since the early 1950's some support activities used revolving funds to finance their operations from the sales of goods and services (22:44).

While comparisons can be drawn between the earlier revolving funds and DBOF, there are some differences in the way they are operated. Under DBOF, the intention is to operate under the following guidelines:

1. all support activities will be in revolving funds,
2. activities in a revolving fund pass along all their costs (only costs related to maintaining war mobilization requirements will retain direct appropriated funding),
3. operators will be free to purchase support from either organic or commercial sources as long as direct and indirect costs are fairly compared. (22:46-47)

In this new environment, support units are the primary providers while operations units are the primary customers. Ultimately, all defense support will be available on a fee-for-service basis through the DBOF.

Initially, eight support activities were included under DBOF when it was implemented on 1 October 1991. The eight activities were: commissaries, supply operations, supply depots, depot maintenance, base operating support, training, medical, and recruiting (27). Only the first four were finally included in DBOF since they had the necessary data available. Determining the unit costs were deemed too difficult for the other four so they were left out of DBOF.

While current systems record data required to implement Unit Cost Resourcing and DBOF, using that data successfully to implement these new systems is a difficult task. The main drawback within DoD is the abundance of various accounting systems. There are more than 80 disparate, unlinked financial systems in use within DoD that are identified under the Federal Managers' Financial Integrity Act (26:11). Over 200 ancillary systems provide other financial information (26:11).

While there is much data available, the main problem is trying to identify the correct data to use for accurate and useful forecasting. Another stumbling block is encountered in trying to identify relevant costs to charge on a project. Relevant costs can be defined as any costs that are avoidable if an alternative is not chosen (17:36).

Closely related to relevant costs is the concept of marginal cost pricing. If marginal cost pricing is used to charge costs for a project, only the additional cost incurred in providing a service or product should be passed on to the customer. The idea behind the use of marginal cost pricing is that a unit with the lowest marginal (extra) cost should be selected to provide the required service. Pricing based on marginal cost promotes a more efficient allocation of scarce resources. For CSC, this translates into passing on to customers the marginal cost incurred for the engineering and installation of telecommunications systems.

If the provider is only charging the customer for the marginal cost, the fixed cost of an activity must be funded through other means. Many expenses are fixed costs in the short-run and should not be considered part of a service fee. If a service is to be provided at the lowest additional cost to DoD, the service charge should reflect only the extra or marginal costs of providing that service. Because DBOF (in its current form) includes fixed and variable costs in its charges it is not consistent with the principle of marginal cost pricing.

Unit Cost Resourcing (UCR). UCR is a management control technique that relates funding levels to outputs (21:14). This management system uses the unit cost, or cost per output concept that all costs incurred in an activity, or within a function, should be related to an output of the activity (13:4). While the basic concept is fairly straightforward, implementation has proved to be rather complex.

DBOF is a revolving fund that operates using the management control techniques of Unit Cost Resourcing (UCR). Therefore, in order to operate under DBOF, support units must use UCR. However, an organization does not have to use DBOF to implement the practice of unit cost resourcing. UCR is a practice that businesses in the private sector have long used to enable managers to make better use of a company's resources. Without knowing how much a product is contributing to a company's bottom line, a manager may continue an activity even though that activity causes the business to lose money.

Reimbursements. Currently CSC uses a reimbursement or fee-for-service style of accounting for services provided. This is somewhat different than the new DBOF style of accounting. As utilized by CSC, fee-for-service charges a customer the marginal cost of producing an end item. Therefore, overhead costs, and in some cases civilian and military pay, are not passed on to the customer.

Costs that are reimbursed to CSC for Engineering and Installation (E&I) services are listed in Figure 2.1. For example, if CSC installed a LAN for a Navy unit the following costs would be passed through to that unit: civilian pay, TDY/Travel, supplies, depot reparables, equipment, and actual contract costs. On the other hand, military pay, asset depreciation, contract administration, and transportation would not be passed through to a Navy unit.

Type of Charge	Air Force	Non-Air Force DoD	Non-DoD Federal
Civilian Pay	No	Yes	Yes
Military Pay	No	No	Yes
TDY/Travel	Yes	Yes	Yes
Asset Depreciation	No	No	No
Supplies, Depot Level Reparables, and Equipment	Yes	Yes	Yes
Actual Contract Costs	Yes	Yes	Yes
Contract Administration	No	No	Yes
Transportation	No	No	Yes

Figure 2.1: Reimbursable Costs (1:4)

All of these costs are typical of the types of expenses incurred by CSC when engineering and installing a telecommunications system. The next section of this chapter provides an abbreviated look at the twelve commodities CSC engineers and installs.

Commodities Installed by CSC

CSC's Systems Telecommunications Engineering Managers (STEMs) are responsible for providing systems engineering consultation for Major Commands and bases Air Force wide (5). The STEM office is a cell of engineers within CSC who act as technical consultants to help define, integrate, and ultimately implement telecommunication requirements (5). In addition to providing Engineering and Installation (E&I) services for the Air Force, CSC also provides E&I services for other DoD organizations as well as Non-DoD Federal Agencies, such as the Federal Aviation Administration (FAA).

Services provided by CSC include long range Command, Control, Communications, and Computer Systems (C^4), architectural planning, on-site engineering, manpower projections, training forecasts, and budgeting for project and/or program objective memorandums (POM) (5). The following is a brief description of the 12 commodities CSC engineers and installs (For a more in-depth description of each commodity, refer to Appendix A):

1. Local Area Networks (LANs) - A telecommunications system within a specific geographical area, designed to allow a number of independent devices to communicate with each other over a common transmission media (6).

2. Information Transfer Architecture (ITA) - This is also referred to as cable plant or outside plant systems. It can include copper, fiber or coax cable and terminating end points, long haul, and line-of-sight systems (3:7). Examples of ITA are the cable required to support the base telephone system as well as other voice systems, air traffic control, and weather systems, to name a few (37).

3. Network Management Systems (NMS) - The process of controlling and auditing the traffic and processes of a

network (18). Networks managed include: Local Area Networks, Wide Area Networks (WAN), Campus Area Network (CAN), and Base Area Network (BAN).

4. Automated Data Processing Systems - General purpose, commercially available data processing equipment and the systems created by them (18).

5. Land Mobile Radios (LMRs) - LMR systems are primarily used for command and control operations to facilitate information transfer within functional areas, i.e. Security police, Air Traffic Control, Maintenance, etc. (18).

6. Video Systems - Video transmission is primarily used for either security monitoring, briefing visual aids (weather vision), or information interchange (18).

7. Long Haul Communications - Communications which permit users to convey information on a worldwide basis and bridge long distances to provide service between bases or between areas (18).

8. Switching Systems - Used to switch information (route it to the user) in either voice or data format (18).

9. Security/Alarm Systems - Security/alarm systems consist of electronic surveillance devices that detect intrusions into an area, survey a protected area, alert security police personnel of an intrusion or entry, and provide a means of alarm assessment (18).

10. <u>Messaging Systems</u> - Provides information transfer with writer-to-reader message and E-mail service for organizational and individual messages (18).

11. <u>Secure Voice/Data Systems</u> - Secure voice communications are provided into the AUTOSEVOCOM or, for on-base communications, through specially engineered arrangements using dedicated lines and dial-up connections with modified tactical secure voice equipment (18).

12. <u>Air Traffic Control and Landing Systems (ATCALS) /Weather Systems</u> - ATCALS provide aircraft with take-off, enroute, and landing guidance, airspace surveillance and aircraft separation required for safe and efficient all-weather flying conditions (18).

While the above list of commodities is not all inclusive, it does account for the majority of the work performed by CSC. The next section of this chapter explains the various methods that are available to estimate costs.

Types of Cost Estimating Methods

There are several ways to estimate costs, including: analogy, grass roots or engineering build-up, and parametric. Analogous and parametric models can be used in the early phases of a project, {i.e., Concept Exploration (CE), Demonstration and Validation (Dem/Val), and Engineering and Management Development (EMD)}. On the other hand the grass roots or engineering build-up method is better used during later phases of a project when more data is available to estimate the cost. Figure 2.2 gives a graphic representation of which methods are used depending on the phase of a project.

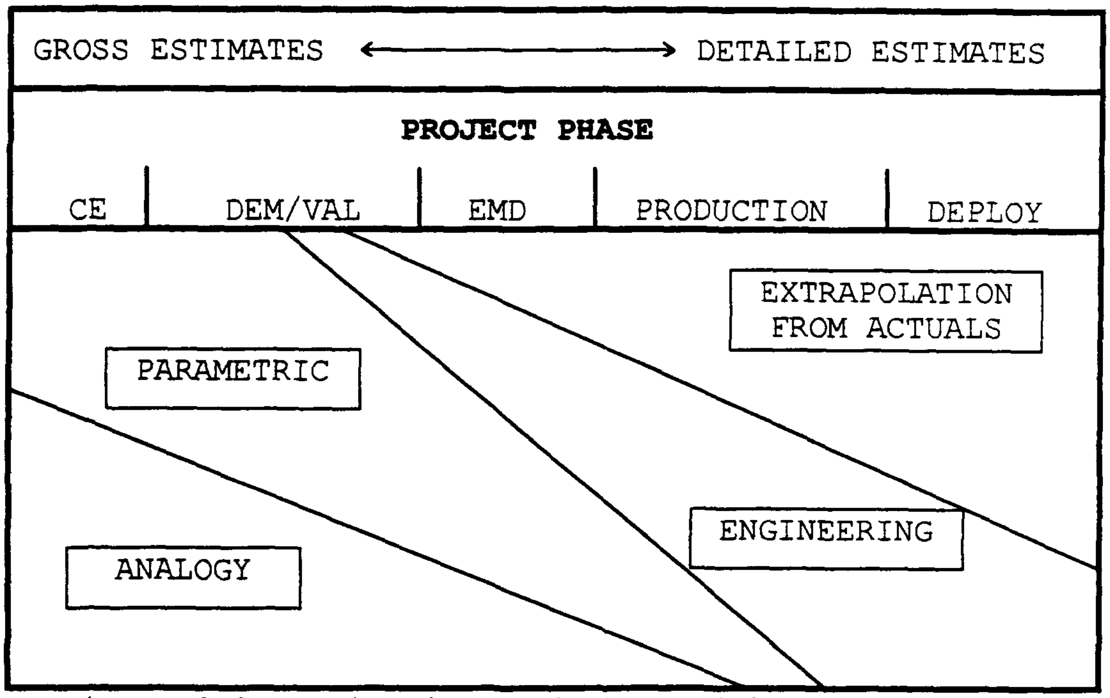

Figure 2.2: Estimating Methods Used in Each Phase (28)

Analogous Method. The "analogous" or "comparative" method takes into consideration that no new program, no matter how advanced represents a totally new system (1:3-24 to 3-25). To use this type of modeling, an existing or past project that is similar is compared to the new project being considered. The differences in technology as well as any physical construction changes are analyzed and an estimate is produced for the new system. By using as many parts or sub-systems as possible from an existing system it is often possible to produce a reasonable estimate.

While this may produce good results at times, there are two limitations to the analogy approach. First is the requirement for a detailed program and technical definitions of both the analogous system as well as the system being estimated (8:3-24). Without this information it becomes increasingly difficult to make an accurate comparison of the two systems. Second, once the technical assessment has identified the analogous system, actual cost data on that system must be acquired (8:3-25). Without technical data from the original system, trying to add costs for the portion of any new requirements becomes a nearly impossible task.

Grass Roots or Engineering Build-Up. The second type of modeling approach is the grass roots or engineering build-up model. Grass roots estimating consists of breaking a project down into all of the discrete activities, tasks, and/or operations that must be performed, and then making estimates of the labor, material, and other resources required to accomplish each (10:10-22). This method is employed in later stages of system development when more actual costs are available and the system is better defined.

An underlying assumption of the grass roots method is that system costs can be predicted with a great deal of accuracy based on the costs of individual subsystems. While this may give an accurate estimate later on in the production of a system, early estimates can not be made due to the lack of actual cost data and due to a lack of detail early in a system's development. Another limitation is the amount of time it takes to collect and analyze the large amount of data necessary to develop a grass roots estimate.

Parametric Cost Models. The parametric method of estimating is normally appropriate for use when there is limited technical definition of a project or when time constraints prohibit a more detailed estimating approach (10:10-19). Therefore, this method is used very early in the planning stages of a project when a rough estimate is sufficient. In order to use a parametric model, historical data is needed to establish the relationship between the dependent variable (cost) and the independent variable(s).

For example, if we are building an automobile it wouldn't be necessary to estimate the cost of every nut and bolt to calculate an estimated cost. Using a parametric model we would just include the items that might be significant drivers of the total cost, such as: the engine size, chassis weight, and body type to name a few. Based on the historical relationship of these items to cost, a cost estimating relationship (CER) can be developed for each of the items and constructed into an overall parametric model.

The major advantage of estimating the cost in this manner is that the major portions of an estimate are captured in a short amount of time and with limited program definition (8:3-23). So, if an interested customer calls CSC requesting an estimate for a Local Area Network (LAN) CSC can provide a reasonable estimate by asking for limited information about the system, i.e., computer requirements, software requirements, etc.

There are limitations to parametric models. The model captures cost at a very high level within the work breakdown structure (WBS) so changes in areas such as design and manufacturing cannot be reflected in the estimate (8:3-23). A second limitation is that the estimate may not be separable into individual component parts of the Work Breakdown Structure if such a breakout is necessary for the customer (10:10-20).

As described previously, the intent of this research is to develop a parametric model that can be used to give a rough estimate to a customer in need of a particular communications system. The next section of this chapter explains how CSC utilizes cost estimating methods.

Estimating Methods Used by CSC

Different methods are in use to estimate costs for various commodities that CSC engineers and installs. One method currently used is a man-hour approach. This involves extensive detail which causes many hours to be expended calculating the number of man-hours required to install the system. Even with the extensive detail identifying the man-hours, the estimates have proven to be inaccurate.

For other commodities a grass roots model is utilized to ascertain an estimate. The most current model for Information Transfer Architecture (ITA) uses a very detailed spreadsheet that calculates the various types and sizes of cables; number of splices; buildings entered; ducts and manholes installed; along with various equipment requirements. According to one expert, the model usually produced estimates that were higher than actual costs and has therefore fallen out of use (7).

In some cases the commodity CSC installs is fairly new and a model has not yet been developed. By maintaining records of costs for installing systems over the next two to three years, historical data can be accumulated and then used to develop a working parametric model.

Previous Research. We could find no research available related to the use of cost estimating models within the fee-for-service environment and communications systems.

Numerous research efforts analyze other recently developed cost policies, namely Unit Cost Resourcing (UCR) as well as the impact of the Defense Business Operations Fund (DBOF) on developing cost estimates.

None of the methods examined dealt with a command similar to CSC. The research currently available makes use of UCR and/or DBOF while they focus on such areas as: the Professional Continuing Education (PCE) program within the Air Force Institute of Technology's School of Systems and Logistics; logistic support activities; information management; Military Airlift Command (now reorganized as the Air Mobility Command); Naval Base Operations Support Cost Allocation; unit costing in Navy shipyards; military construction and family housing programs; transportation funding; and Navy stock funds.

Summary

The Defense Business Operations Fund (DBOF) requires service organizations to charge customers based on the level of service provided, similar to practices seen in the civilian business sector. In order for support units to survive in this new environment, it is imperative that they provide quality services and products to their customers, the operations units. If they are unable to do so, units will have the option of seeking out better services, whether it is through another DoD organization or a civilian business.

Communications System Center uses engineering buildup and man-hour approaches to estimate costs, methods that have not been very accurate. In order to give customers a better idea of the costs that will be incurred when installing a new communications system, CSC needs to develop a more accurate cost estimating approach.

While several models have been developed for use by other units in various areas of operations within the military, none of the models address the type of operation that CSC conducts. The remainder of this research effort will center on developing cost estimating relationships designed specifically to model the engineering and installation costs incurred by CSC for various commodities.

III. Methodology

Chapter Overview

This chapter reviews the methods used to answer the investigative questions introduced in Chapter I (and re-stated below). Discussed in this chapter are the processes used to narrow the scope of the study to a manageable size and the methods used to determine plausible cost drivers for the various electronic communication systems under study. Also discussed are the data collection procedures and the various statistical analysis techniques used to estimate the relationship between the postulated cost drivers and the historical costs.

Background

Problem Statement. The Communications Systems Center (CSC) currently uses both man-hours and engineering build-up approaches to estimate Engineering and Installation costs. The estimates provided have not accurately reflected actual costs and have caused budgeting problems for CSC customers. Because of the recent change to a fee-for-service funding environment, the need for accurate historical data for cost estimating is also new. This means that collection of the historical cost data needed to build a parametric model for estimating engineering and installation costs will require a lot of effort. In most cases, possible cost drivers have not even been defined for collection so a major part of the effort will go toward defining plausible cost drivers.

Research Objective. The objective of this thesis is to first determine what plausible cost driver categories exist for a reduced set of commodities that are installed by the CSC. For those commodities that have enough historical data available, an attempt will be made to develop a parametric cost estimating equation to replace or supplement the current estimating approach. The results of this research will also provide CSC with a set of hypothesized cost drivers for each of the reduced set of commodities that are installed on an on-going basis. Collection of additional data over the next several years will allow statistical analysis at some future date with the goal of developing valid cost estimating relationships for all of the CSC commodities.

Investigative Questions

To fulfill the research objectives, the following questions must be answered:

1. Which commodities installed by CSC units are in need of better estimating methods?

2. What plausible cost drivers can be identified for each commodity in question, for both immediate and continuing data collection?

3. What historical cost and engineering data is available right now for each commodity in question?

4. For commodities with data available, what statistically valid cost estimating relationships exist, based on historical costs and the hypothesized cost drivers?

Methodology Employed

The process of building a parametric cost model (one based on a cost estimating relationship) requires a reservoir of historical cost data. The intent is to use that cost data to quantify the relationship between cost drivers and the cost of the overall system. The data can also be used to evaluate the strength of that relationship using proven statistical estimating techniques.

The Communications Systems Center currently engineers and installs (and estimates cost for) the twelve commodities covered in Chapter II and restated below.

1. Local Area Networks (LANs)
2. Information Transfer Architecture (ITA)
3. Network Management Systems (NMS)
4. Automated Data Processing Systems

5. Land Mobile Radios (LMR)
6. Video Systems
7. Long Haul Communications Systems
8. Switching Systems
9. Security/Alarm Systems
10. Messaging Systems
11. Secure Voice/Data Systems
12. Air Traffic Control/Weather Systems.

The following sections discuss the methodology employed to answer each of the investigative questions stated above.

Question 1. Which commodities installed by CSC units are in need of better estimating methods? To answer this question we traveled to HQ CSC, Tinker AFB, Oklahoma, and met with systems engineers, project managers, and a representative of the financial management branch of HQ CSC. At this series of meetings we asked free-flowing questions intended to identify the commodities that would benefit most from a parametric cost estimating relationship. Typical of questions asked at these meetings were:

a. Which commodities represent the highest volume (both past and present) of business for CSC?

b. How different are the original cost estimates from final cost for each commodity?

c. Which commodities have the highest priority for developing a parametric cost model?

d. Where within CSC is the institutional support greatest for a new series of cost models and how does that impact the overall priority?

The information gleaned from the above questions was used to come to an understanding with CSC on which cost models would be pursued in the limited time available.

Question 2. What plausible cost drivers can be identified for each commodity in question, for both immediate and continuing data collection? After identifying the commodities with the highest priority, we made contact with the lead engineer in each area to discuss the modeling effort. After returning from HQ CSC we further explained to the lead engineer (via telephone and e-mail) the concepts of how cost drivers are identified and used in the building of a parametric cost model. The lead engineer, in turn, led round-table discussions with his coworkers to brainstorm possible cost drivers relevant to their particular system.

Out of the initial brainstorming sessions came a set of postulated cost drivers. We then used an extended series of telephone calls, e-mail messages, and more brainstorming sessions to refine the list of cost drivers and develop definitions so that data collection on the installed systems could begin.

Also included in the brainstorming was an attempt to postulate cost driver behavior. For each of the cost drivers in question we wanted to identify a cost behavior that both we and the engineers deemed plausible. For example, increasing the number of computers installed on a LAN will likely result in increased cost, but at a decreasing rate. Having an idea of the particular behavior of a cost driver allowed us to make certain transformations in the data in order to improve the fit of the estimating equations.

Question 3. What historical cost and engineering data is available right now for each commodity in question? After the data definitions were agreed upon, we developed a data collection format for each of the commodities that were of immediate priority. The data collection format was used by project managers at the Communications Systems Center while searching through files for the relevant cost driver information.

Project managers were allowed four weeks to collect data for the initial commodity (LANs). While much of the data was expected to be readily available at the outset of the effort, we discovered that in some cases the historical costs and other information had not been gathered at project completion as it should have been. This lack of information required project managers to review paperwork files on a case-by-case basis in order to find the information needed.

Data collection problems on the initial commodity ranged from differing interpretation of data definitions to incomplete data and estimates of cost rather than the actual historical costs required by a parametric cost model. Because of the data collection problems, we shortened the collection effort on subsequent commodities to a two week period. We hoped that shortening the collection time would allow us more time to review the data for reasonableness and to check for consistency in the data collected.

Question 4. For commodities with data available, what statistically valid cost estimating relationships exist, based on historical costs and the hypothesized cost drivers? With valid historical data in hand we used the computer programs SAS, STATISTIX 4.0, and Microsoft EXCEL that are available at AFIT to analyze the data and build the parametric models. For our purposes, we used EXCEL to perform several of the data manipulations before analyzing the data using SAS and STATISTIX. The first adjustment was to change all of the pass through costs to constant (1992) dollars so that the model will estimate in dollars of that particular base year.

Price Level Changes. We selected the Implicit Gross Domestic Product (GDP) Price Deflator as a price index for adjusting the historical costs into 1992 constant dollars. We considered the use of several other price indexes but found that many of the components of the Producer Price Index (PPI) were too specialized for our use. A weighted index was considered but we found that given the low inflation rates experienced over the past three years, there were no material differences between a weighted index and the GDP Deflator. In addition, the Implicit GDP Deflator is considered by many economists to be the best **single** measure of changes in the overall price level (31:11).

We chose the 1992 base year because it was the year of the earliest data collected and because the Implicit GDP Deflator is being updated to a 1992 base year, a change that will simplify model maintenance over the next five years until the base year is changed again. Current and historical values for the price deflator are listed in the Survey of Current Business, published by the US Department of Commerce each quarter. We used the deflator value for the year of 1992 (121.1) as the base value (36:25). For years in which the deflators for all four quarters are available (i.e. 1993), we used the composite deflator for that year (124.2). For years with less than four quarters available (chiefly 1994 at this point) we adjusted to constant dollars using the latest value available (currently 125.7 for the first quarter of 1994). An example of how the inflation adjustment is made follows:

IF: 1993 cost $300,000
1993 deflator 124.2
1992 deflator 121.1 THEN:

$$993Cost \times \frac{1992\,Deflator}{1993\,Deflator} = \$292{,}512$$ 1992 Dollars. (3.1)

This step converts the raw data into a constant dollar figure so that the effects of inflation can be removed from the model. The output of the parametric model will be in 1992 dollars and will be multiplied by the ratio of latest deflator/base deflator to adjust the estimate to current dollars. For example, an estimate of $292,512 from the model would equate to a 1993 cost of:

$$\$292{,}512 \times \frac{1993\,Deflator(124.2)}{1992\,Deflator(121.1)} = \$300{,}000$$ 1993 Dollars. (3.2)

Maintenance of the model will require quarterly updating with the latest deflator from the Survey of Current Business.

Statistical Measures. Any model constructed must first of all make logical sense if it is to be used to predict costs. But quantifying the strength of a particular model requires the use of some standard statistical measures. While these measures allow models to be compared to one another and to an overall standard, they cannot be used in isolation to defend a model that "fits" well but has no logical foundation.

The particular fitting technique used to estimate the coefficients of the regression surface is based on the "least-squares best fit" (LSBF) approach. LSBF seeks to minimize the squared differences between the data and the regression surface. The least squares approach is the most widely used method for fitting data to a mathematical model.

We used the following statistical measures to test the various models:

F-score: This value measures the ratio of mean squares of the model to the mean squares of the error terms (MSR/MSE). It is a measure of explained variation to unexplained variation. Significant F-scores can be found in an F-table, and depend on the number of degrees of freedom of the numerator and denominator in the ratio. A single f-score is calculated for the model as a whole. SAS provides an associated p-value with the F-score. The p-value is the smallest significance level for which we can reject the null hypothesis. We used a significance level of .1 as our benchmark so that p-values less than .1 represent a significant result in the F and t statistical measures.

t-score: This value measures the significance of the estimate of each individual term in the model. Significant t-scores are found in a t-table and depend on the number of degrees of freedom available and the confidence level required. SAS also provides an associated p-value for each t-score and we used p-values less than .1 as indications of a significant t-score.

R-square: The coefficient of multiple determination (R^2) represents the ratio of explained variation to total variation (SSR/SSTO). It is a percentage measure of how much of the total variation is explained by the model. Higher values are preferred but there is no particular "cutoff" below which the model is invalid. R^2 values range from zero to one and a regression surface of perfect fit would have a value of 1.

Many other statistical measures exist and will be discussed as necessary in Chapter IV. The importance of the current discussion is to understand that we are willing to accept a 10% chance (α=.1) of making a type I error by rejecting an otherwise true null hypothesis. We use this level as a guideline for including certain independent variables in the cost estimating relationships, but not as an absolute rule to determine which variables will be excluded.

Summary

This chapter has outlined the methodology followed to answer the investigative questions posed in Chapter I. We detailed the processes used to identify and define plausible cost drivers and discussed collection of historical data from projects completed by the Communications Systems Center. The final section of this chapter discussed the transformations used to normalize the data into 1992 dollars before analysis and concluded with a short presentation of some of the statistical measures used in the effort.

IV. Findings and Analysis

Chapter Overview

This chapter presents the results of the research effort along with a statistical analysis of the cost estimating relationships that we were able to construct. This chapter is arranged into five major sections. The first section presents the reduced list of commodities installed by the Communications Systems Center (CSC) for which we attempted to build models. Three sections follow with the results of the model building effort for each commodity identified as priorities by CSC. The final section is a short summary of the findings.

The Commodities

The Communications Systems Center engineers and installs the 12 commodities discussed in Chapter II. Comprehensive definitions of the individual commodities are included in Appendix A. After our initial meetings with the project leaders and engineers at CSC, we agreed to pursue model development on Local Area Networks (LANs), Information Transfer Architecture (ITA), and Network Management Systems (NMS).

These three commodities were selected based on: 1) the importance of each to the future business base of the CSC, 2) the belief by us, system engineers, and project managers that these commodities represented the best probability of successful model development, and 3) the level of support expected from those offices within CSC. At the time this decision was made, CSC personnel felt that each of the three commodities in question had an abundance of data available to support the development of a cost estimating relationship.

Local Area Networks (LANs)

The LAN commodity was pursued first in hopes that lessons learned in the initial development would save time later. The initial effort involved combining our knowledge of cost estimating with the LAN engineers' knowledge of LAN design characteristics and physical attributes. After numerous iterations of a definition list, we finally agreed on the possible cost drivers and definitions presented in Appendix B.

We provided CSC with a data collection format for the LAN commodity, along with the list of definitions for each possible cost driver. Continued discussion with the LAN engineers resulted in an expected cost driver behavior for each relevant item in the definition list. The postulated behavior of each cost driver is the last item in each definition of Appendix B. Throughout the definition lists and this chapter, there is a standardized notation used to symbolize each cost driver's expected behavior. The standardized notation is detailed in Figure 4.1. In the cases below, the first sign in the parentheses represents the sign of the first derivative of the relationship between the independent variable (the cost driver) and the dependent variable. The second sign represents the sign of the second derivative of the same relationship.

Notation	Behavior Indicated
(+,+)	Cost increases at an increasing rate
(+,0)	Cost increases at a constant rate
(+,-)	Cost increases at a decreasing rate
(-,+)	Cost decreases at a decreasing rate
(-,0)	Cost decreases at a constant rate
(-,-)	Cost decreases at an increasing rate
(cat)	Indicates a categorical effect upon the dependent variable (cost).

Figure 4.1: Notation Describing Cost Driver Behavior

Data Collection Results. CSC tasked the 485th Electronics Installation Squadron (EIS) at Griffiss AFB, NY, and the 1845th EIS at Tinker AFB, OK to collect data on the installation of LAN systems. The two squadrons were allowed four weeks to complete the tasking. The results of the LAN data collection effort are detailed in Appendix B, following the LAN definitions.

The collection effort yielded only 14 observations, none of which represented a complete, start to finish engineering and installation of a LAN project. Installation of one of the projects had not yet begun. Because of the limited number of observations, the amount of variation necessary to identify with confidence the effects of a number of the cost drivers was not present. The limited variation in the categorical cost drivers was such that it appeared the variation was more the result of differences in the way the data were collected than true variation within the category.

Another common problem with the LAN data was the apparent use of estimates, rather than actual historical costs in the data collection. Examples of this were the rounded-off amounts for supplies and travel & per diem. Training costs were estimated at $10,000 for every project completed by the 485th EIS, and at $0 for every project done by the 1845th EIS.

When we investigated the limited number of observations and patterns in the observations, CSC assured us the data were the best available and that the number of observations were all that were available since CSC had been working on installation of LANs for two years at most. In that time, all of the work completed had been geared to upgrading existing systems.

After some discussion, we and our contacts at CSC came to the realization that a credible cost estimating relationship could not be built to estimate E&I costs of LANs with the limited data that were available. That understood, they committed to undertake a more comprehensive data collection effort as future projects are completed. We agreed to propose a modeling framework that might be used for future analysis as sufficient data becomes available.

Hypothesized LAN Model. We discussed briefly in Chapter II that CSC is sometimes able to pass on military pay and civilian pay, depending on the customer being served. Non-Air Force Department of Defense (DoD) customers will reimburse CSC for civilian pay, while non-DoD customers will reimburse both civilian and military pay expenses. To allow for these possibilities requires that the estimate of the E&I cost be added to the relevant payroll estimates.

To accomplish that end, the LAN (as well as ITA and NMS) models are organized in the following format:

1. A basic estimate that would apply to a project for an Air Force unit, in base-year dollars that are then adjusted for inflation. This estimate is dependent on a

cost estimating relationship and is henceforth called the estimate of Air Force Pass Through Costs.

2. A "premium" is added for civilian pay when the project is non-Air Force, but still within the DoD. This premium is the product of the **engineering** hours CER and the civilian pay labor factor used by CSC.

3. An additional "premium" for military pay is added when the project is outside of the DoD. This premium is the product of the **installation** hours CER and the military pay labor factor used by CSC.

The heart of the model is the CER that estimates Air Force Pass Through Costs in base-year(1992) dollars. The hypothesized model that relates cost drivers to AF Pass Through Costs (PTC) is:

$$\begin{aligned} PTC_{LAN} &= b_0 + b_1 HardwarePieces \\ &+ b_2 \#ComputersPurchased + b_3 \#ComputersInstalled \\ &+ b_4 CableLength * CableType + b_5 \#Hubs + b_6 PerDiemRate \end{aligned} \tag{4.1}$$

where: PTC_{LAN} is stated in 1992 dollars; HardwarePieces is the sum of the number of bridges, routers, gateways, faxes, and printers; CableLength*CableType is an interaction variable and all other variables are as represented in the LAN definitions.

To adjust PTC_{LAN} to current dollars, multiply PTC_{LAN} by an inflation index using the current Implicit GDP Deflator divided by the 1992 Implicit GDP Deflator.

If the project is to be done outside the Air Force, add the premium for engineering (civilian) pay to Equation (4.1) above. This premium is based on the product of engineering hours and the civilian labor factor. We expect LAN Engineering Hours to be estimated by the following CER:

$$
\begin{aligned}
EngHours_{LAN} &= b_0 + b_1 EngNodes + b_2 Hubs \\
&+ b_3 ComputersInstalled + b_4 CableType
\end{aligned}
\tag{4.2}
$$

where: EngNodes is the sum of bridges, routers, and gateways, and CableType is a categorical variable.

If the project is for a non-DoD agency, add to the sum of the estimates for Equations (4.1) and (4.2) the additional premium for installation (military) pay. This premium is based on the product of installation hours and the appropriate military labor factor. We expect LAN Installation Hours to be estimated by the CER:

$$
\begin{aligned}
InstHours_{LAN} &= b_0 + b_1 CableLength + b_2 EngNodes \\
&+ b_3 ComputersPurch + b_4 InstNodes + b_5 Hubs
\end{aligned}
\tag{4.3}
$$

where: InstNodes is the sum of computers installed, fax systems, and printers.

LAN Summary. If the data collection efforts for the LAN commodity had been sufficient, we would have been able to provide estimates for the b_i terms in Equations (4.1) through (4.3). At present, due to data limitations, the estimates for those terms and the knowledge of their statistical significance is unknown. The next section of this chapter discusses the Information Transfer Architecture (ITA) commodity.

Information Transfer Architecture (ITA)

The definitions for the ITA commodity were pursued in earnest as soon as the data collection for LANs began. We applied the lessons learned from the definition gathering process for LANs and set forth establishing definitions for ITA. As with LANs, we combined the engineers' knowledge of the ITA system's characteristics and physical attributes along with our knowledge of cost estimating. We narrowed the initial list down to a workable level after many iterations. The possible cost drivers and definitions for ITA are presented in Appendix C.

After the definitions were agreed upon we provided CSC with a data collection format along with the definitions for each possible cost driver. During data collection, we continued our discussion with the ITA engineers to determine the expected behavior for each of the cost drivers in the definition list. As with the LANs, the postulated behavior for each ITA cost driver is included as the last item in each definition listed in Appendix C.

Data Collection Results. Once again CSC tasked the 485th Electronics Installation Squadron (EIS) at Griffiss AFB, NY and the 1845th EIS at Tinker AFB, OK to collect historical data from previously installed ITA systems. The results of the ITA data collection effort are detailed in Appendix C, following the ITA definitions.

The collection effort yielded a total of 65 observations from the two squadrons. Of these 65, 37 were received from the 485th EIS at Griffiss AFB, NY and the remaining 28 were supplied by the 1845th EIS at Tinker AFB, OK. The size of the ITA jobs ranged from very small (100 feet of cable) to very large (53010 feet of cable). After analyzing the data, it was apparent some of the data would be unusable for various reasons which are discussed in the next few paragraphs.

The main reason observations were deleted from the set was due to a lack of sufficient data. Most of these deleted observations were missing information for engineering and installation travel and per diem costs.

There were also several projects completed by Air National Guard (ANG) units. For many of these projects the cost for installation travel and per diem was not available.

In one case the 215th EIS from Everett, WA installed 630 feet of cable in Aviano, Italy for a total cost of $1364. The cost for this job was so low because travel and per diem was not included. In cases such as this, the pass through cost of the project was understated by a significant amount and could not be used for analysis.

On some projects, a customer may have already had the equipment or cable on hand for a project. In that case the cost of those items is not included in the total cost. These projects were deleted if the cost of materials could not be supplied in some other way since it is not accurate to estimate the costs of a system when substantial parts of the project (material and cable) are not included.

On one project the unit doing the installation also conducted a significant amount of training at the same time. This added tremendously to the total hours it took to complete the project, thereby adding considerably to the AF pass through costs and misrepresenting the number of installation hours required for a project of that size. The unit in question was unable to identify what portion of the installation hours represented training, so the project was deleted from the data set.

It should be noted that before any of the observations were dropped from the set, discrepancies were identified and forwarded to the 485th EIS and 1845th EIS for clarification.

In many cases it was impossible to recover any more data for projects completed by ANG units. Some of the data initially provided seemed inconsistent with the majority of data. These items were flagged, investigated, and updated in the data set if the initial information proved to be incorrect. In this way, many observations that would have caused the model to give inaccurate results were adjusted and used in the model.

Model Development. To estimate costs for an Information Transfer Architecture (ITA) project we used the same format of the three cost estimating relationships (CERs) as presented in the LAN section. The three CERs estimate Air Force (AF) pass through costs, civilian pay costs, and military pay costs. As noted in Chapter II, the cost for civilian and military pay is not passed through on every project. The cost of civilian pay is passed through on everything except Air Force projects, while military pay is only included on Non-DoD projects.

In the data set analyzed, all of the projects were for Air Force units so civilian pay and military pay expenses were not included in the pass through costs. However, this section will develop CERs to predict cost for civilian and military pay because CSC is expected to need this information in the future.

AF Pass Through Cost CER. As stated in the introduction to ITA, we exchanged notes with the engineers at the Communications Systems Center (CSC) to get a better understanding of an ITA system's characteristics. The histogram in Figure 4.2 shows the distribution of pass through costs collected in the data set. Only two of the projects had pass through costs in excess of $240,000.

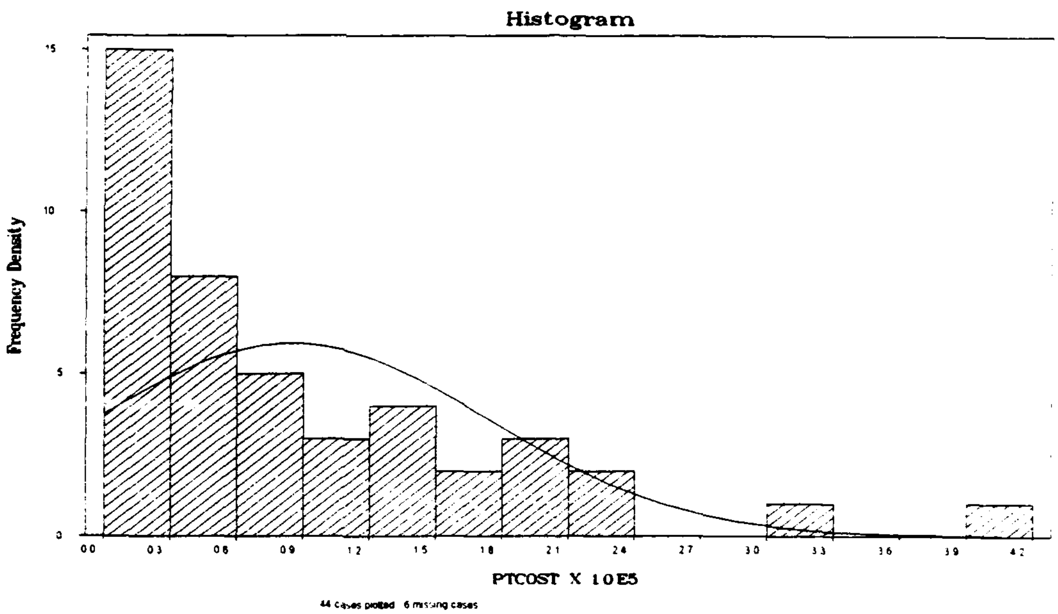

Figure 4.2: ITA Pass Through Costs

With a list of possible cost drivers and their postulated behavior, a CER was developed to estimate the pass through cost for an ITA system installed at an Air Force location. We expected the significant variable in an ITA CER to be cable pair miles, fiber strand miles, ducted feet of cable, buried feet of cable, number of terminals, number of splices, and the daily per diem rate paid in the installation location.

The variables above with a (+,-) cost behavior were transformed by taking the square root of each prior to regressing against pass through cost. The square root transformation was used because the costs incurred by these variables, taken one at a time and all else held constant, were expected to increase pass through costs but at a decreasing rate. In other words, if it costs $1000 to install 50 feet of cable it will obviously cost more to install 100 feet but it would probably be less than $2000.

In the case of terminals and splices the behavior was expected to be linear; the cost would increase but at a constant rate (+,0). Therefore, the time (thus cost) required to complete 100 splices is expected to be double that required for 50 splices.

The initial regression indicated that several of the predictor variables were insignificant indicators of cost. In addition, a check of the regression diagnostics (DFFITs and DFBETAs values) for each observation identified six outliers in the data set. The outliers were investigated and corrections were made to the data set. Further discussion of the outlier identification process, as well as the interim steps taken to identify insignificant variables, is included in the Information Transfer Architecture (ITA) User's Guide that constitutes Appendix E.

With the data corrected, the final regression coefficients are as shown in Table 4.1.

Table 4.1: Statistics for ITA AF Pass Through Cost CER
Dependent Variable = AF Pass Through Cost
R^2=.84, Adjusted R^2=.81
F-score=36.2

Predictor Variables	**Coefficient**	**t-score**	**p-value**	**Variance Inflation Factor**
Intercept	-74348.5	-1.74	.09	
Square Root CableMiles	1049.32	1.65	.11	5.8
Square Root FiberMiles	8656.38	6.00	.00	1.4
Square Root Duct Feet	283.464	2.05	.05	1.6
Splices	2.61543	2.44	.02	6.3
Square Root PerDiem	7292.09	1.62	.11	1.1

The statistics in Table 4.1 indicate this CER is very significant. With the exception of the square root of cablemiles and the square root of per diem, all of the variables are significant at the 5% level or better. We leave cablemiles and per diem in the equation because they are known to be important components of cost for an ITA project.

Therefore, the CER that will predict the Pass Through Cost of an Air Force ITA project is:

$$\begin{aligned} PTC_{ITA} = &-743485 + 1049.32\left(\sqrt{CableMiles}\right) + 8656.38\left(\sqrt{FiberMiles}\right) \\ &+283.464\left(\sqrt{DuctFt}\right) + 2.61543\left(Splices\right) + 7292.09\left(\sqrt{PerDiem}\right) \end{aligned} \tag{4.4}$$

To adjust PTC_{ITA} to current dollars, multiply PTC_{ITA} by an inflation index using the current Implicit GDP Deflator divided by the 1992 Implicit GDP Deflator. The result is an estimate of cost for an Air Force ITA project in current year dollars.

Civilian Pay CER. As was the case with LANs, the estimate for ITA pass through costs will sometimes include civilian and military pay. Although the data collected had no projects for which those categories were included, as CSC seeks to broaden its business base they are likely to have to estimate such costs in the future. Because the engineering workforce is overwhelmingly civilian and the installation workforce predominantly military, we will again use engineering hours as the estimator of civilian pay and installation hours as the estimator for military pay.

The histogram in Figure 4.3 shows the distribution of engineering hours in the data set. Two of the observations in the data set are very wide outliers at four and six standard deviations above the mean.

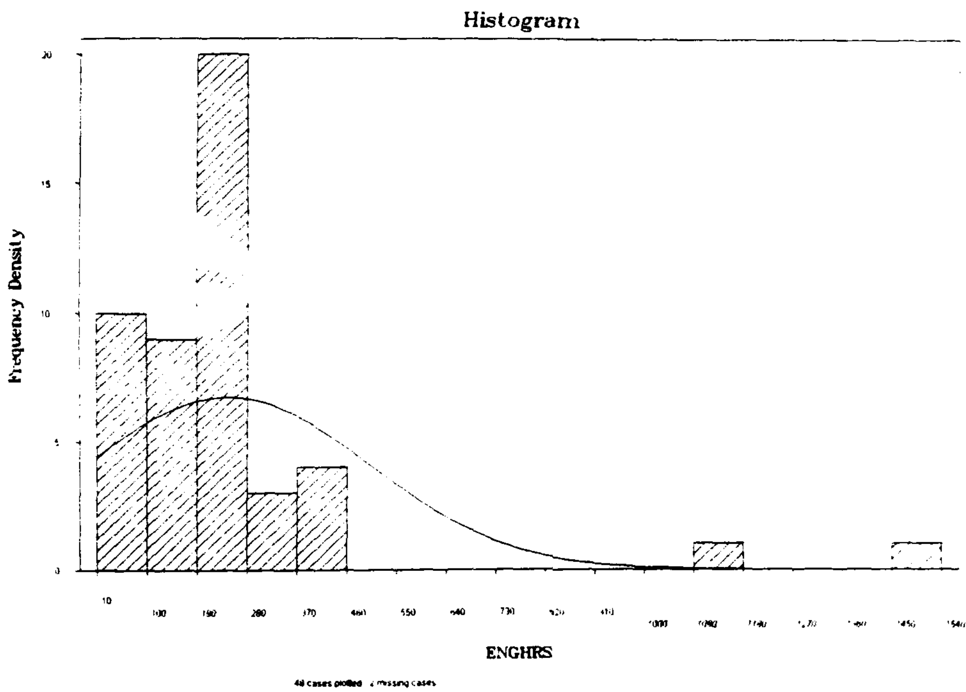

Figure 4.3: Full Data Set of ITA Engineering Hours

Given the size of these two projects, especially the number of miles of cable involved and the number of splices required, it is entirely reasonable that the number of engineering hours required is accurate. That these jobs are unusual in the set of fifty projects is not to say that they are unreasonable.

With those two outliers omitted from the data set (for presentation purposes only), the histogram shows a somewhat more normal distribution of engineering hours (Figure 4.4).

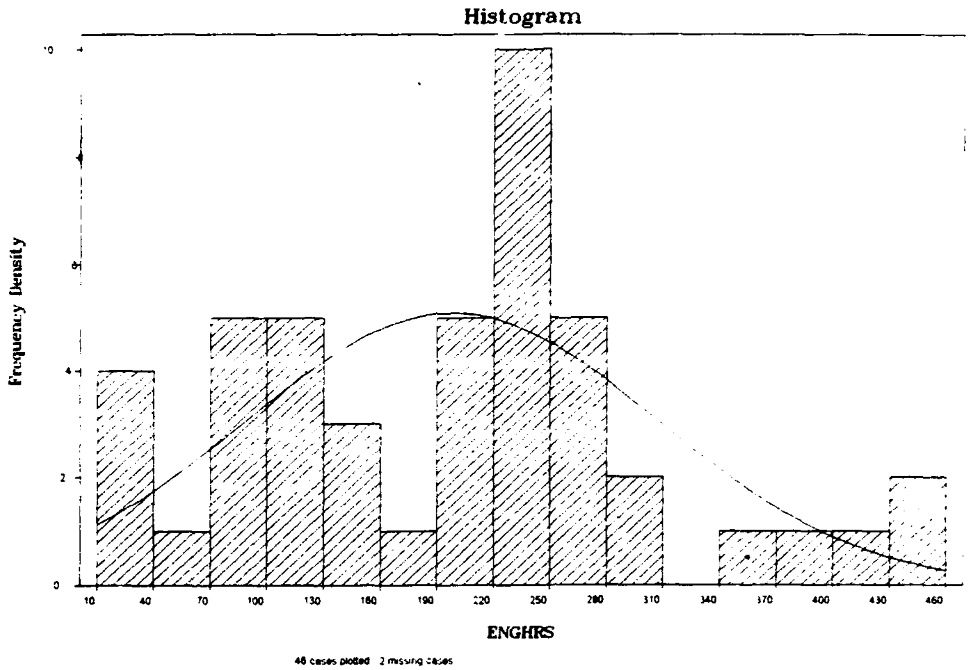

Figure 4.4: ITA Engineering Hours with Outliers Omitted

Estimating engineering hours presents some peculiar difficulties because so many of the possible drivers of engineering effort are subjective measures that would be very difficult to collect. For example, the abilities and experience level of the engineer(s) on a project are difficult to objectively determine. Also, two identical projects may take very different levels of engineering effort based on the amount of preparatory work that must be done to update the base blueprints as part of the project requirements.

With these constraints in mind, we expected the most significant indicators of engineering hours to be the number of terminals and splices in the project, the total number of miles (cable miles + fiber miles), and total feet of cable to be installed. From an engineering hours standpoint, both terminals and splices are indicators of project complexity while miles and total feet indicate the extent of a project. We expected all four of those drivers to increase at a decreasing rate (+,-) with respect to engineering hours.

We analyzed several different transformations relevant to that behavior and settled on a multiplicative CER with the results in Table 4.2. As shown, the relationship is significant, but the adjusted R^2 is relatively low. The miles and total feet variables are important components of engineering hours and are left in the model even though they do not test significant in the current formulation.

While use of this estimating relationship over time will produce unbiased estimates, it may not prove to be a very accurate predictor on any single project. However, the magnitude of the forecast error for ITA engineering hours to the overall forecast is not likely to be significant because engineering hours is a small component of pass through cost.

Table 4.2: Statistics for ITA Engineering Hours CER
Dependent Variable = ln(EngHrs)
R^2=.25, Adjusted R^2=.18
F-score=3.46

Predictor Variables	**Coefficient**	**t-score**	**p-value**	**Variance Inflation Factor**
Intercept	2.70854	2.04	0.05	
lnTerms	0.23881	1.75	0.09	1.5
lnSplices	0.18787	1.48	0.15	6.3
lnMiles	-.17529	-1.08	0.29	8.6
lnTotal Feet	0.18417	1.15	0.26	3.5

It is interesting to note that the sign of the coefficient for miles is negative. This would seem to indicate that adding miles of cable to an installation project would decrease engineering hours. In reality, some multicollinearity exists between the independent variable miles and the other independent variables. This makes it very difficult to isolate the effects of a single variable on the number of engineering hours required on a project.

From the standpoint of the entire CER, we found no significant outliers as were discovered in the CER for pass through cost. The statistics above simplify to Equation (4.5) for estimating engineering hours:

$$EngHrs_{ITA} = \frac{15 * Terminations^{.23881} * Splices^{.18787} * TotalFt^{.18417}}{Miles^{.17529}} \tag{4.5}$$

The premium for civilian pay is the product of engineering hours and a civilian labor factor that is determined by CSC.

Military Pay CER. Development of the CER to predict installation hours necessary to perform a project was accomplished in the same manner as the previous CERs discussed. The histogram in Figure 4.5 shows the distribution of Installation Hours of the projects in the data set.

We expected the number of hours required to install an ITA project to be directly related to the total miles of cable (cable miles + fiber miles), the number of ducted feet of cable, the number of buried feet of cable, the number of terminals in a system, and the number of splices in the project.

After transforming the variables according to their expected behavior, we determined that only ducted and buried feet of cable along with the number of splices were significant predictors of the number of installation hours.

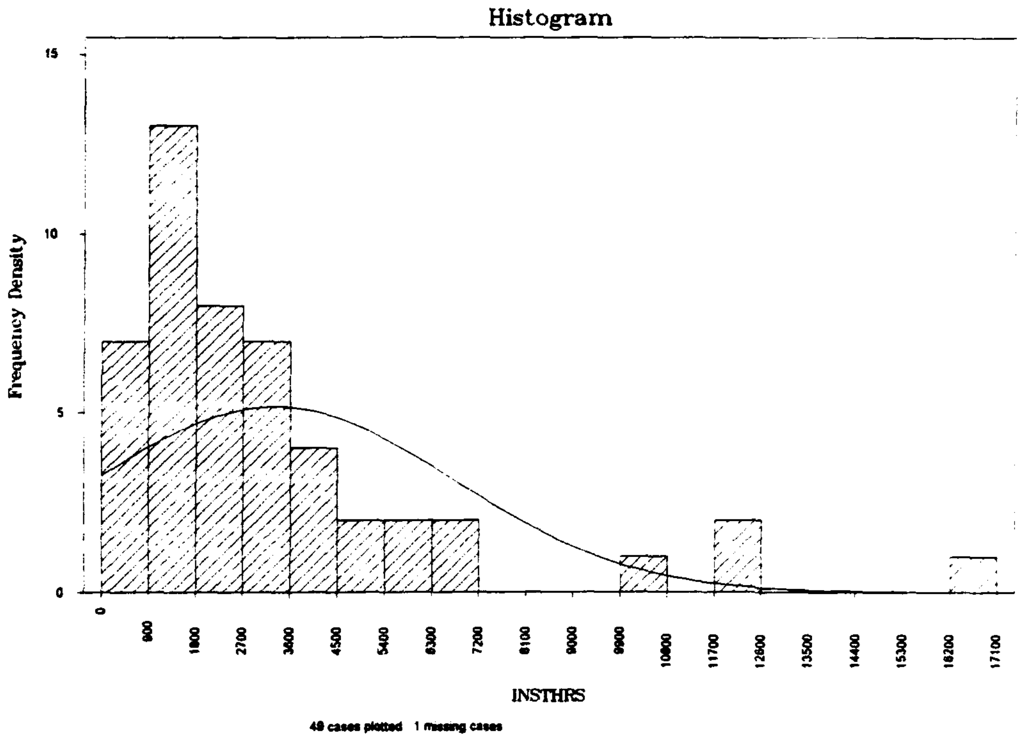

Figure 4.5: ITA Installation Hours

The number of terminations in a project are closely related to the number of splices used, so all of the necessary information is captured by the splices variable. Cable miles and fiber miles were combined because their effects would be identical on the number of installation hours required on an ITA project.

Table 4.3 lists the coefficient estimates from the regression analysis and is followed by the Installation hours CER.

Table 4.3: Statistics for ITA Installation Hours CER
Dependent Variable = Installation Hours
R^2=.66, Adjusted R^2=.64
F-score=29.2

Predictor Variables	Coefficient	t-score	p-value	Variance Inflation Factor
Intercept	-54.5984	-0.09	.93	
Square Root Duct Feet	23.4921	3.04	.00	1.3
Square Root Bury Feet	17.4077	2.92	.01	1.2
Splices	0.15171	5.61	.00	1.3

Therefore, the CER to predict Installation Hours of an ITA project is given by Equation (4.6):

$$\begin{aligned} InstHrs_{ITA} &= -54.5984 + 23.4921(\sqrt{DuctFeet}) \\ &+17.4077(\sqrt{BuryFeet}) + .15171(Splices) \end{aligned} \tag{4.6}$$

The premium for military pay is the product of Installation Hours and the military labor factor that is determined by CSC.

<u>ITA Summary</u>. In total, the ITA model consists of an estimate of Pass Through Costs (Equation 4.1) that is adjusted for inflation, a premium (in current dollars) included for the cost of engineering manhours, and an additional premium (also in current dollars) included for the cost of installation manhours. Greater detail of the

model's development is contained in the ITA Model User's Guide (Appendix E). The next section of this chapter will discuss model development for the Network Management Systems commodity.

Network Management Systems (NMS)

The NMS commodity was the last pursued of the three in this effort. While much of the preliminary definition work was attempted concurrently with LANs and ITA, progress on the NMS definitions went more slowly. We also found ambiguity in the types of cost drivers suggested by CSC as being plausible indicators of E&I cost.

After continued discussion with the NMS systems engineers, we discovered that no network management systems had been installed by CSC. The NMS unit had only recently been started and they were hoping that a parametric cost model would provide the tool,they needed to make early estimates of system cost. They proposed conducting a survey of commercial businesses (their competitors) for information on cost driver behavior and E&I data.

Aside from the fact that commercial businesses currently engaged in the NMS business would have no incentive to give away proprietary information, any data collected may not be accurate enough to build a reliable model. In addition, any model constructed based on contractor data would only be useful in predicting the cost incurred by a contractor operating in a commercial environment, and would have little connection to the E&I cost that CSC is required to pass through to its customers.

To provide a reliable model under such circumstances would be impossible and would detract from the reputation of a parametric model. As in the case of LANs, the NMS engineers agreed to collect data on future projects using a set of definitions and a data collection format that we would work with them to provide.

NMS Definitions and Format. The definitions for plausible cost drivers in the NMS commodity are the result of many iterations and discussions with the NMS engineers. The definitions can be referenced in Appendix D, along with a data collection format that will be used to collect the data for analysis in the future.

As before, the postulated behavior of the individual cost drivers is included at the end of each definition, using the notation explained in Table 4.1. A notable difference in the types of cost drivers expected for NMS is that many of the NMS cost drivers are categorical in nature, as opposed to the continuous type more often expected in LANs and ITA.

The large number of cost drivers for the NMS commodity may make it difficult to collect the necessary data and to develop a model for estimating the basic cost. Another drawback is that available information may not accurately reflect the impact of variations in the scale of output upon cost. This difficulty could decrease the accuracy of the engineering and installation hour CERs which are required for an overall estimate. The format for compiling the estimate will remain unchanged from that detailed in the sections on LANs and ITA.

Summary

This chapter presented the results of our investigation along with the process we followed to estimate the coefficients of the cost estimating relationships (CERs) used to model the engineering and installation costs of Information Transfer Architecture (ITA) projects. Cost models for Local Area Networks (LANs) and Network Management Systems (NMS) could not be built because of an insufficient amount of data. A modeling framework for all of the commodities installed by CSC was presented so that future efforts may be implemented in the same fashion.

V. Conclusions and Recommendations

Chapter Overview

The initial intent of this research effort was to develop several parametric cost models for the Communications Systems Center (CSC) at Tinker AFB, Oklahoma. The need for more accurate estimating methods was brought about by the large cut-backs in defense spending due to military "downsizing." This created a cost saving focus within the Department of Defense (DoD) financial community which led, in part, to the concept of the Defense Business Operations fund (DBOF). The intent of DBOF is for DoD to operate more like a business whereby support units "sell" their products to operational units or other users. Operational units will continue to receive appropriations to pay for the goods and services they require.

When DBOF is implemented, support units will have the challenge of competing with other support units and commercial providers to offer quality goods and services at reasonable prices. If operational units wish to purchase goods and services more cheaply through other means, such as another government service or civilian business, they will have that option. The end result is that support units could lose customers causing them to go out of business. Therefore, units like CSC must be able to provide more accurate estimates up front so their customers are better able to budget their funds accordingly.

Conclusions

The initial stages of the research effort required identification of the various commodities engineered and installed by CSC. The 12 commodities that were determined to be the bulk of their work are listed in Appendix A with detailed definitions. Of these 12, three were initially chosen as priorities. The three commodities chosen were: Local Area Networks (LANs), Information Transfer Architecture (ITA), and Network Management Systems (NMS).

To develop plausible Cost Estimating Relationships (CERs) for the commodities, we worked with the engineers, project managers, and area specialists at CSC to gain a better understanding of the systems. Through our discussions we were able to define plausible cost drivers for each of the three commodities. Cost driver definitions are included in Appendices B-D.

Once cost drivers were defined and a collection format was set up, the 485^{th} Electronics Installation Squadron (EIS) at Griffiss AFB, New York and the 1845^{th} EIS at Tinker AFB, Oklahoma collected data for LANs and ITA. Initially, data was collected for LANs with limited success, mainly due to a lack of systems previously installed. While we were unable to develop a complete model for LANs, we hypothesized

CERs for LAN Pass Through Costs, Civilian Pay, and Military Pay. As more systems are engineered and installed, CSC will hopefully be able to take this information and develop usable CERs.

The ITA data collection effort was more fruitful as data was gathered from 65 projects. This data was analyzed using regression analysis and CERs were developed to estimate ITA Pass Through Costs, Civilian Pay, and Military Pay. The full equations are included in Chapter IV as well as Appendix E (User's Guide).

The last commodity analyzed was Network Management Systems (NMS). While LANs and ITA had systems engineered and installed in the past, CSC had yet to complete any NMS projects. Therefore, it was impossible to develop any CERs for this commodity. The lack of consensus on cost driver behavior for NMS limited work on this commodity to cost driver definitions that will be used in future data collection efforts.

Recommendations

Based on the results obtained with the Information Transfer Architecture model, the use of a parametric approach to cost estimating in the early stages of a project would enable CSC to improve their up-front cost estimates. Better estimates would improve customer satisfaction, which would in turn broaden the business base that CSC serves.

Under the fee-for-service environment taking hold throughout the Department of Defense, a broader business base of satisfied customers would help CSC remain a viable service organization.

We believe that building a series of models to estimate the cost of the various commodities is a valid research objective. We recommend that CSC pursue further development by obtaining in-house expertise in this area. As of this writing, CSC had recently lost their single position for a person formally educated in the modeling process. Whether their requirement for an Advanced Academic Degree (AAD) position will be reinstated or not remains to be seen.

Much work remains to complete the task of building a series of CERs for the various commodities engineered and installed by CSC. A significant part of this work will involve identifying cost drivers for the remaining commodities and collecting the historical data required to develop the cost estimating relationships that characterize a parametric cost model. In some cases, CSC may have to enhance their present costing approaches rather than rely on a parametric model developed with insufficient data.

Appendix A: Commodity Definitions

Local Area Network(LAN)

Local Area Networks are telecommunications systems within a specified geographical area designed to allow a number of independent devices to communicate with each other over a common transmission topology. LANs are usually restricted to a specific functional area or small geographical areas, i.e. rooms, buildings. LANs are employed for electronic mail, file management, application, network drives, data sharing, data processing, and message transfer via Defense Data Network (DDN). Depending on the implementation, these communications networks can provide internal interchange of voice, data, graphics, video, or other forms of electronic messages.

Information Transfer Architecture(ITA)

Information Transfer Architecture is a base-wide digital network that serves the needs of all base users and provides an interface with off-base systems. Its primary feature is the distribution of the switching, transmission, and connectivity capabilities of the baseline into a base wide digital network of multiple nodes, connected through high capacity transmission systems.

Network Management System (NMS)

Network Management Systems control and audit the traffic and processes of a network. It includes the configuring of devices on a network, establishing passwords, limiting access to peripherals and files and maintaining audit trails. Network management function categories are: fault, configuration, security, performance, and accounting management. The network management structure also has both hierarchical and distributed features so that it can effectively manage a variety of worldwide sub networks, systems, and services.

Automatic Data Processing Equipment

Automatic Data Processing Equipment includes general purpose, commercially available data processing equipment and the systems created by them. This is a subsystem of the Automatic Data System (ADS) which is an assembly of procedures, processes, methods, or techniques united by regulated interaction. Terminals, stand-alone PCs, microprocessors, mini computers, host computers (UNISYS 2200, MicroVAX, AT&T 3B2, etc.) and other automated processing devices comprise this group.

Land Mobile Radios/Systems (LMR)

LMR systems are primarily used for command and control operations to facilitate information transfer within functional areas, i.e. Security Police, Air Traffic Control, Maintenance, etc. Radio networks (nets) are established on the basis of functional agencies, each with its own radio system, antenna, code words, and call signs; several independent 'nets' exist on bases supporting different missions. Base Support Radios are intended for static location use and include pagers, single and multi-channel two-way radios, mobile radios, etc. Combat Deployable radios are intended for combat-related tasks and are used by forces identified for contingency and deployment.

Video Systems

Video transmission is primarily used for either security monitoring, briefing visual aids (weather vision), or information interchange via Community Antenna Television (CATV). Video systems are broadcast in nature, connecting several TV monitors to a camera via coaxial cable distribution system. These include various Closed circuit Television (CCTV) applications such as spot and area surveillance, Video Teleconferencing (VTC), and distribution of locally developed special purpose programs (video taped or live educational material).

Long Haul Communications

Communications which permit users to convey information on a worldwide basis and bridge long distances to provide service between bases or between areas. They are generally characterized by higher levels of users (including National Command Authorities), stringent performance requirements (higher quality circuits), longer distance between users (up to global distances), higher traffic volume and density (larger sizing of switches and trunk cross sections), and fixed or recoverable assets. Long haul communications systems include satellite, Defense Data Network (DDN), on-base trunks, microwave, Base Central Test Facility (BCTF), etc.

Switching Systems

Switching systems are divided into two parts - voice and data. There are four basic ways to switch (or route) information to the user: circuit, packet, message, and channel.

Packet switching involves the transmission of fragmented blocks of standard size bits or 'packets', that travel the same or different route, whereby a channel is occupied only for the duration of transmission of the packet. These packets are then reassembled at the receiving side into the original message. Like circuit switching, packet switched communications provide access to Integrated Service Digital Network (ISDN) services, long haul DoD, and commercial switched and packet services.

Message switching involves formatting messages into long data streams which are transmitted as a unit to a switching center or moved from node to node. Transmission does not occur until the circuit has been established and is available. Also, when received by an intermediate station, the entire message must be received, stored, and then forwarded to the next station when a circuit is available.

Channel switching is a powerful form of switching that transmits entire channels at top levels of the hierarchy, from one location to another.

Circuit switching is a direct, electrical connection between calling and called stations that is established and maintained for the duration of the information transfer or until the connection is released. Circuit switching involves the use of Private Branch Exchange (PBX), sophisticated computers whose primary purpose is to provide a communications switching capability. The present PBX is an integrated digital voice and data circuit switched device that features non-blocking switch matrices for a given number of line/trunk terminations (ports).

Security/Alarm Systems

Security/alarm systems consist of electronic surveillance devices that detect intrusions into an area, survey a protected area, alert security police personnel of an intrusion or entry, and provide a means of alarm assessment. These systems improve surveillance capability and enhance physical security of critical military resources, storage, and alert sites at selected bases worldwide. Some examples include the Base Intrusion Security Systems (BISS) and the Joint Services Interior Intrusion Detection Systems (JSIIDS).

Messaging System

The objective of the Air Force Defense Messaging System is to provide information transfer (including narrative, graphical, and data) with writer-to-reader message and E-mail service for organizational and individual messages. These services include message preparation, directory services, coordination, authentication, distribution, storage, and retrieval. Organizational message service includes command & control messages as well as messages exchanged between organizational elements requiring release and precedence approval by designated officials. Individual, or E-mail messages, do not generally commit or direct organizations and do not have precedence features.

Secure Voice/Data Systems

Secure voice communications are provided into the Automatic Secure Voice Communications (AUTOSEVOCOM) or, for on-base communications, through specially engineered arrangements using dedicated lines and dial-up connections with modified tactical secure voice equipment. This includes STU-IIIs, a portable, self-contained, secure voice communications unit with data capabilities. A number of bases are Red Switch equipped, a voice telephone switching system that provides secure voice services within protected secure enclaves, isolates channels to prevent crosstalk, and is installed to allow for processing red (unencrypted) secure conversations.

Secure Data Communications systems include Link encryption devices that provide wide area communications security and Link security mechanisms that protect the link between users' computers or terminals and host computers or wide area access points. In addition to link encryption, some mechanisms, like Low-Cost Encryption and Authentication Devices (LEAD) and STU-IIIs are also used to access secure data services. Cryptographic equipment is also used to encrypt the link and provide a secure path between the Telecommunication Center (TCC) terminal and the AUTODIN Switching Center (ASC).

ATCALS/Weather

ATCALS provide aircraft with take-off, enroute, and landing guidance; airspace surveillance; and aircraft separation required for safe and efficient all-weather operations. Information from a variety of on and off-base sources, including: radar systems, air-to-ground radios, dedicated computer systems, and landlines are used by controllers to perform air traffic control functions. While some of these facilities use telephone lines, others (such as radar facilities) use dedicated cables for video and communication purposes.

Weather information is normally provided either by the National Weather Service (NWS) or the Air Weather Service (AWS). The data compiled from various locations is transferred over leased lines to a central collection point. The information is then distributed to base weather stations via facsimile, teletype, automated systems, and video monitoring systems.

(Definitions Provided by CSC)

Appendix B: LAN Definitions, Format, and Data

To the best of your ability reconstruct and provide project information and cost based on the parameters defined below.

Project Number: This is self explanatory.

Base Name: Name of Base where the LAN was installed.

Installation Start Year: Calendar year of installation start.

Building Type: This parameter consists of two alternatives. Concrete (C) or other (O). Choose the one that most closely matches the building type into which the LAN will be installed. (cat)

Cable Type: This parameter has four possibilities. Fiber Optic (F), Twisted Pair (TP), Coax (C) or Other (O). Choose that which most closely matches the type of LAN installation. (cat)

Cable Length: This refers to the total feet of cable used for this LAN installation. (+,-)

Number of Bridges: Total number of bridges used in this LAN installation. (+,+)

Number of Routers: Total number of routers used in this LAN installation. (+,+)

Number of Gateways: Total number of gateways used in this LAN installation. (+,+)

Number of FAX Systems: Total number of network FAX Systems in this LAN installation. (+,0)

Number of Computers Purchased: Total number of Computers Purchased for this LAN installation. (+,-)

Number of Computers Installed on the LAN: Total number of Computers Installed on the LAN. This is the total number of computers on the LAN, both purchased and installed plus those already available which were installed. (+,-)

Number of Hubs: Total number of Hubs used in this LAN installation. Equipment such as Cabletron MMACs, Synoptics 5000, etc. If this equipment has a bridge, router, or gateway card, include it in those numbers above. (+,+)

Number of Printers: Total number of Printers installed on the LAN. (+,0)

Physically Secure LAN: Does this LAN require Physical security (Y/N). Examples: Top Secret LAN, Secret LAN, etc. (cat)

Daily Per Diem Rate Paid: This is the actual per diem rate that was paid to installers while away from their home base at the installation site. This will sometimes be $0 when an installation is completed at the home base of the installation unit. (+,+)

Environmental Controls Needed: Does the installation of a LAN require the installation of specific Environmental Controls (Y/N). These would include air conditioning or heating systems. (cat)

Number of Computers Needing Software: This is the total number of software packages purchased for the computers in this LAN installation. This would include Office Automation Software as well as any specific software for the functional area, like CAD software for a CE LAN installation. (+,-)

Floor / Rack Space Available: Is there Floor or Rack space available for the LAN equipment being installed. (Y/N) (cat)

Special Power Requirements: Was special power condition equipment (such as UPS, or expensive surge protectors) installed for the LAN equipment. (Y/N) (cat)

Throughput Requirements: This is broken down into High, Medium, and Low speed traffic (H/M/L). These correspond to greater than 50Mb/s -> High, 50Mb/s to 5Mb/s -> Medium, and less than 5Mb/s -> Low. (cat)

Dial-In Access Required: Was there a Dial-In capability installed for access to the LAN. (Y/N) (cat)

Engineering Man-hours In-House: The man-hours expended by CSC engineers to accomplish project-related workload.

Installation Man-hours In-House: The man-hours expended by CSC installers to accomplish project-related workload.

Base Allied Support Costs: Consists of costs for the base civil engineering "support" work that a base would do in preparation of CSC's installation. Examples would be minor construction (less than $300K) and such items as purchase of telephone poles, sand, gravel, manholes, ducts, power upgrade etc.)

MCP Support Costs: Military Construction Program costs are major construction projects such as building a building, a major upgrade to a facility, and an extensive manhole and duct system costing over $300K.

Equipment Costs In-House: Purchase of major equipment items (the end items of equipment) or systems where 3080 dollars are required. In-house refers to government provided equipment, either through the supporting ALC, or other government acquisition activity where equipment is provided as part of the overall program.

Installation Hardware Supplies In-House: Hardware items such as cable, connectors, nuts , and bolts, supplied through the CSC warehouse.

Engineering Travel and Per Diem In-House: Travel expenses plus the per diem paid for CSC engineering teams when in TDY status to support project workload.

Installation Travel and Per Diem In-House: Travel expenses plus the per diem paid for CSC installation teams when in TDY status to support project workload.

Quality Assurance Travel and Per Diem: Travel expenses plus the per diem paid for CSC quality assurance teams when in TDY status to perform quality assurance evaluation duties related to the project.

Equipment & Software: Other equipment and/or software that might be required that is being furnished by the customer (i.e. computers, modems etc.) and their yearly recurring 3080 costs.

O&M, Rentals, Special Tools: Rental of special equipment (such as concrete cutters, trenchers etc.) to be used during installation or special tools that must be purchased for the O&M unit to operate and maintain the equipment, including recurring costs.

Telecommunications Connectivity: Cost of transferring/starting service to the local telephone company or long-haul vendor, including recurring costs.

Training: Training required for operational or maintenance personnel at the base.

Pass Through Costs: This is the sum of the previous cost categories and any costs incurred for which no category was specified. This represents the amount of expenses that were passed on to the installation customer. It is very important that all cost figures be based on actual, historical costs. All dollars placed here represent the one-time nature of E&I expenses.

Yearly Recurring Costs: The annually recurring costs (such as dedicated phone lines, software updates etc.) associated with operating and maintaining the system.

The following cost driver behavior conventions are used at the end of each postulated cost driver:

(+,+) Cost increases at an increasing rate

(+,0) Cost increases at a constant rate

(+,-) Cost increases at a decreasing rate

(-,+) Cost decreases at a decreasing rate

(-,0) Cost decreases at a constant rate

(-,-) Cost decreases at an increasing rate

(cat) indicates a categorical effect upon the dependent variable (cost).

Appendix B: LAN Definitions, Format, and Data

	485th Project Number	Base Name	Installation Start Year	Bldg. Type (C/O)
1	1376A2B0	BOLLING	not started	C
2	2534A3B0	RAF LAKENHEATH	94	C
3	2535A3B0	RAF LAKENHEATH	94	C
4	0823A3B0	LANGLEY AFB	94	C
5	2451A3B0	RAF MILDENHALL	94	C
6	1382A2B0	RAMSTEIN AB	94	C
7	2454A3B0	RAMSTEIN AB	94	C
8	2455A3B0	RAMSTEIN AB	94	C
9	1936A2B0	SPANGDAHLEM	94	C
10	2177A3B0	WRIGHT-PATT AFB	93	C
	1845th			
11	1764A3D0	ALTUS AFB, OK	94	C
12	0008A4D0	USAFA, CO	94	C
13	0012A4D0	USAFA, CO	94	C
14	0013A4D0	USAFA, CO	94	C

Appendix B: LAN Definitions, Format, and Data

	Cable Type (F/TP/C/O)	Cable Length (Ft)	# of Bridges	# of Routers	# of Gateways	Number of FAX Systems	Number of Computers Purchased
1	FO, C, TP	40	0	2	0	0	2
2	TP	1000	0	6	1	0	2
3	TP	500	0	9	0	0	1
4	FO, C, TP	2000	0	2	0	0	0
5	FO, C, TP	500	1	1	0	0	1
6	FO, C, TP	400	1	1	0	0	13
7	FO, C, TP	300	1	1	0	0	1
8	FO, C, TP	1500	0	1	0	0	0
9	C, TP	3000	0	20	0	0	20
10	FO, C, TP	N/A	0	1	0	0	0
11	TP	13000	2	0	0	2	34
12	F / TP	25000	2	0	0	0	120
13	TP	0	0	0	0	0	1
14	TP	0	0	0	0	0	0

Appendix B: LAN Definitions, Format, and Data

	Number of Computers Installed on LAN	# of Hubs	# of Printers	Physically Secure LAN (Y/N)	Daily Per Diem Rate Paid	Environmental Controls Needed (Y/N)	Number of Computers Needing Software
1	2	2	0	Y	H	Y	0
2	2	0	0	Y	H	Y	0
3	1	0	0	Y	H	Y	0
4	0	0	0	Y	H	Y	0
5	1	1	1	Y	H	Y	0
6	13	2	0	Y	H	Y	0
7	1	1	1	Y	H	Y	0
8	0	0	0	Y	H	Y	0
9	20	0	20	Y	H	Y	0
10	0	0	0	Y	H	Y	0
11	36	2	4	N	L	N	36
12	180	4	30	N	M	Y	180
13	15	5	0	N	M	N	1
14	29	2	0	N	M	N	0

Appendix B: LAN Definitions, Format, and Data

	Floor / Rack Space Available (Y/N)	Special Power Req.'s (Y/N)	Throughput Requirement (L/M/H)	Dial-In Access Required (Y/N)	Eng. Manhours
1	Y	Y	M	Y	250
2	Y	Y	M	Y	560
3	Y	Y	M	Y	500
4	Y	Y	M	Y	250
5	Y	Y	M	Y	250
6	Y	Y	M	Y	310
7	Y	Y	M	Y	250
8	Y	Y	M	Y	250
9	Y	Y	M	N	770
10	Y	Y	M	Y	250
11	Y	Y	M	Y	505
12	Y	Y	M	Y	960
13	Y	N	M	N	225
14	Y	N	M	N	225

Appendix B: LAN Definitions, Format, and Data

	Install. Manhours	Base Allied Support Costs	MCP Support Costs	Equip. Costs	Install. Hardware / Supplies Costs
1	520	0	0	8,600	45,800
2	2040	0	0	16,000	
3	2040	0	0	5,200	
4	672	0	0	14,900	140,000
5	640	0	0	13,000	35,000
6	400	0	0	15,300	26,500
7	400	0	0	13,000	35,000
8	640	0	0	13,300	14,300
9	6464	0	0		16,000
10	736	0	0	7,100	66,600
11	350	0	0	0	300
12	1200	300	0	0	5,000
13	160	0	0	0	0
14	160	0	0	0	0

	Eng. Travel and Per Diem Cost	Install. Travel and Per Diem Cost	QA Travel and Per Diem Cost	Equip., Software Etc. Cost	O&M, Rentals, Special Tools, Etc. Cost
1	800	12,100	800	0	0
2	3,750	45,300	1,250	0	0
3	3,750	45,300	1,250	0	0
4	800	1,270	800	0	0
5	1,250	1,360	1,250	0	0
6	1,050	9,400	1,050	0	0
7	1,050	8,800	1,050	0	0
8	1,050	13,000	1,050	0	0
9	3,150	117,920	1,050	0	0
10	1,000	13,480	500	0	0
11	600	500	0	135,000	0
12	5,000	12,500	0	80,000	0
13	2,000	2,000	0	26,000	0
14	2,000	2,000	0	0	0

	Telecomm. Connectivity Cost	Training Costs	Pass Through Costs	Yearly Recurring Costs
1	0	10,000	78,100	7,500
2	0	10,000	76,300	2,400
3	0	10,000	65,500	11,300
4	0	10,000	167,770	2,400
5	0	10,000	61,860	1,900
6	0	10,000	63,300	1,200
7	0	10,000	68,900	1,200
8	0	10,000	52,700	1,100
9	0	10,000	148,120	25,000
10	0	10,000	98,680	1,200
11	0	0	136,400	0
12	0	0	102,800	0
13	0	0	30,000	2,200
14	0	0	4,000	0

Appendix C: ITA Definitions, Format, and Data

To the best of your ability reconstruct and provide project information and cost based on the parameters defined below.

Project Number: This is self explanatory.

Base Name: Name of Base where the ITA was installed.

Installation Start Year: Calendar year of installation start.

Cable Type: This refers to the predominant type of newly installed cable used for this ITA project. The types for this category are: Copper, Fiber, Other (C,F,O)

Cable Pair-Miles: This refers to the sum of {the number of cable pairs installed for each cable segment multiplied by the number of miles (ft/5280)} installed for that particular segment. (Numeric) (+,-)

Fiber Strand-Miles: This refers to the sum of {the number of fiber strands installed for each cable segment multiplied by the number of miles (ft/5280)} installed for that particular segment. (Numeric) (+,-)

Cable Length Installed in Manhole Duct System: This refers to the total length of cable in feet installed in the manhole duct system for this ITA project. (Numeric) (+,-)

Cable Length Direct Bury: This refers to the total length of trenches (each trench can have more than one cable) in feet directly buried (to include boring) for this ITA project. (Numeric) (+,-)

Total Cable Length: This refers to the total length of cable in feet installed for this ITA project; include cable in manholes, direct bury, and other. (Numeric) (+,-)

Rocky Terrain: Indicates whether the ground where the ITA was installed was predominantly rocky terrain or not. (Y/N) (cat)

Number of Terminal Locations: This refers to the number of terminals to be installed or removed for this ITA project. (Numeric) (+,-)

Floor/Wall Penetrations: This refers to the number of floors/walls penetrated for this ITA project. (Numeric)(+,-)

Number of Pairs Spliced: This refers to the total number of splices for each pair cable performed for this ITA project; to include the number of twisted pairs terminated. For example, termination of a 25 pair cable in a building is considered 25 splices. (Numeric) (+,-)

Width of Streets Crossed: This refers to the total feet of streets crossed for this ITA project. (Numeric)

Number of New Manholes Installed: Total number of manholes installed in this project. (Numeric) (+,-)

Total Number of Manholes: This refers to the total number of manholes in this project. (Numeric) (+,-)

Number of New Handholes Installed: Total number of handholes installed in this project. (Numeric) (+,-)

Total Number of Handholes: This refers to the total number of handholes in this project. (Numeric) (+,-)

Length of New Ducts Installed: This refers to the total feet of ducting installed for this ITA project. (Numeric) (For example, 10 ducts in a 100 foot section equals 1000 feet of Ducting.) (+,-)

Daily Per Diem Rate Paid: This is the actual per diem rate that was paid to installers while away from their home base at the installation site. Computed as the sum of off-base lodging and meals, and used as an indicator of the cost of living at the installation sites. This will sometimes be $0 when an installation is completed at the home base of the installation unit.

Engineering Man-hours In-House: The man-hours expended by CSC engineers to accomplish project-related workload. (Numeric)

Installation Man-hours In-House: The man-hours expended by CSC installers to accomplish project-related workload. (Numeric)

Engineering Travel and Per Diem In-House: Travel expenses plus the daily per diem rate for CSC engineering teams when in TDY status to support project workload. ($)

Installation Travel and Per Diem In-House: Travel expenses plus the daily per diem rate for CSC installation teams when in TDY status to support project workload. ($)

Quality Assurance Travel and Per Diem: Travel expenses plus the daily per diem rate for CSC quality assurance teams when in TDY status to perform quality assurance evaluation duties related to the project. ($)

Installation Hardware Supplies In-House: Hardware items such as cable, connectors, nuts , and bolts, supplied through the CSC warehouse.

Cable Cost: This refers to the total cost of cable for this ITA project.

Base Allied Support Costs: Consists of costs for the base civil engineering "support" work that a base would do in preparation of CSC's installation. Examples would be minor construction (less than $300K) and such items as purchase of telephone poles, sand, gravel, manholes, ducts, power upgrade, etc.

MCP Support Costs: Military Construction Program costs are major construction projects such as building a building, a major upgrade to a facility, and an extensive manhole and duct system costing over $300K.

Equipment Costs: Purchase of major equipment items (the end items of equipment) or systems. This includes government provided equipment, either through the supporting ALC, or other government acquisition activity where equipment is provided as part of the overall program or equipment provided by the contractor.

O&M, Rentals, Special Tools: Rental of special equipment (such as concrete cutters, trenchers etc.) to be used during installation or special tools that must be purchased for the O&M unit to operate and maintain the equipment.

Pass Through Costs: This is the sum of the previous cost categories and any costs incurred for which no category was specified. This represents the amount of expenses that were passed on to the installation customer. It is very important that all cost figures be based on actual, historical costs. All dollars placed here represent the one-time nature of E&I expenses.

Appendix C: ITA Definitions, Format, and Data

	Project Number	Base Name	Installation Start Year (FY)	Cable Type (C,F,O)
1	0175A2B0	Antigua AFS	1993	C,F
2	0044A2B0	Tyndall AFB	1994	F
3	0282A2B0	Tyndall AFB	1993	C
4	0280A2B0	Tyndall AFB	1993	F
5	0835A3B0	Langley AFB	1994	C
6	0013A0L0	Bitburg AB	1993	C
7	0576A3B0	Maxwell AFB	1993	C
8	0651A3B0	Langley AFB	1993	F
9	0699A3B0	Maxwell AFB	1993	F
10	0893A3B0	Cape Canaveral	1993	F
11	1763A0D0	Cape Canaveral	1992	C,F
12	1925A9D0	Tyndall AFB	1993	C
13	2030A3B0	Fairchild	1994	C
14	2181A4D0	Langley AFB	1993	C
15	0144A1B0	Einsiedlerhof	1993	C,F
16	0180A2B0	Langley AFB	1992	F
17	0239A0B0	Griffiss AFB	1993	C
18	0306A2B0	Maxwell AFB	1993	C,F
19	0402A7B0	Griffiss AFB	1993	C
20	0037A2B0	Gunter AFB	1993	F
21	0250A2B0	Cape Canaveral	1992	F
22	1900A8D0	Langley AFB	1993	C
23	0107A1B0	Toledo ANGB, OH	1994	C
24	0350A0B0	Wright-Patt AFB, OH	1992	F
25	0448A3B0	KI Sawyer	1993	C
26	1745A2D0	MARCH	1993	C
27	1965A3D0	VANDENBERG	1994	C
28	1719A6D0	LACKLAND	1992	C
29	1526A3D0	EDWARDS	1994	C
30	1803A3D0	NELLIS	1994	C

	Cable Pair-Miles	Fiber Strand-Miles	Cable Length (Ft) Installed in Manhole Duct System	Cable Length (Ft) Direct Bury	Total Cable Length (Ft)	Rocky Terrain (Y/N)
1	3368.0	60.0	35958	0	35958	1
2	0.0	17.0	2802	1200	4002	0
3	420.5	0.0	11485	0	11485	0
4	0.0	314.0	2000	14666	16666	0
5	31.5	0.0	0	1400	1400	0
6	189.5	0.0	0	7050	7050	0
7	545.5	0.0	1200	0	1200	0
8	0.0	81.0	17445	13723	31168	0
9	0.0	2.4	2099	0	2099	0
10	0.0	18.4	8540	1500	10040	1
11	298.0	3.0	4591	0	4591	1
12	1719.7	0.0	5289	2175	7464	0
13	28.4	0.0	3500	9000	12500	0
14	3990.0	0.0	14125	9800	23925	0
15	486.7	19.0	6980	0	6980	0
16	0.0	43.0	7572	0	7572	0
17	717.6	0.0	200	4730	4930	0
18	42.6	14.0	3834	0	3834	0
19	31.7	0.0	200	2800	3000	0
20	0.0	28.8	6200	530	6730	0
21	0.0	43.9	5700	1500	7200	0
22	2435.6	0.0	6825	1450	8275	0
23	1122.0	0.0	12260	8165	20425	0
24	0.0	15.0	3258	0	3258	0
25	649.0	0.0	1170	32670	34440	0
26	2323.0	0.0	8309	765	9074	0
27	41.0	0.0	700	600	1300	0
28	872.0	0.0	7645	520	8165	0
29	167.0	0.0	250	1850	2200	0
30	683.0	0.0	4500	0	4500	0

	Number of Terminal Locations	Number of Floor/Wall Penetrations	Number of Pairs Spliced	Total Width of Streets Crossed (Ft)
1	8	2	24150	0
2	2	0	60	30
3	17	17	6456	0
4	5	0	426	270
5	2	1	600	10
6	15	3	1706	20
7	2	0	14400	0
8	26	11	168	300
9	2	0	48	0
10	9	0	38	0
11	3	0	3320	0
12	5	0	23450	0
13	2	0	60	30
14	16	0	40348	200
15	8	0	19900	0
16	3	0	90	0
17	2	0	6400	60
18	4	0	1406	0
19	2	1	600	40
20	5	0	204	0
21	15	0	348	0
22	12	4	42350	300
23	35	6	29928	2695
24	5	0	102	220
25	11	11	1238	1770
26	46	14	32800	700
27	8	0	650	0
28	2	0	8425	160
29	1	2	1600	185
30	9	0	11700	0

	Number of New Manholes Installed	Total Number of Manholes	Number of New Handholes Installed	Total Number of Handholes	Length of Ducts Installed
1	35	56	0	0	80000
2	0	4	0	0	0
3	13	13	0	0	35000
4	0	7	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	3	0	0	0
8	0	4	3	7	2000
9	0	2	0	0	0
10	0	12	0	0	0
11	0	9	0	0	0
12	0	31	0	4	0
13	0	11	0	0	0
14	0	30	0	0	0
15	0	11	0	2	0
16	0	17	0	0	0
17	0	3	0	0	0
18	2	4	0	0	6200
19	0	1	0	0	0
20	0	5	0	0	0
21	0	13	0	0	0
22	0	26	0	0	1548
23	17	17	11	11	32420
24	0	8	0	0	0
25	0	9	0	5	0
26	9	14	4	4	21594
27	0	3	0	0	0
28	2	26	0	0	5900
29	0	1	0	0	0
30	0	19	0	0	0

	Daily Per Diem Rate Paid	Engineering Man-hours	Installation Man-hours	Engineering Travel and Per Diem Cost
1	151	275	3926	919
2	79	237	1730	1087
3	74	121	1995	0
4	74	247	7019	0
5	117	140	56	0
6	102	260	4480	No Record
7	74	222	1712	955
8	113	358	6493	881
9	74	35	490	340
10	93	168	1426	1200
11	93	49	1376	600
12	74	Contract	10356	Contract
13	85	271	2632	5033
14	113	1531	17095	2058
15	.	454	3747	485 DET 1
16	111	195	2416	No Record
17	90	410	2844	0
18	74	191	2400	755
19	90	194	830	0
20	77	244	2123	No Record
21	93	235	1858	No Record
22	113	123	12195	No Record
23	86	1121	5126	1800
24	93	100	1008	No Record
25	68	239	2812	No Record
26	88	243	3401	900
27	113	235	988	
28	87	155	3957	
29	140	213	1118	
30	107	244	3528	

	Installation Travel and Per Diem Cost	QA Travel and Per Diem Cost	Installation Hardware / Supplies Costs	Total Cable Cost (inc. w/supplies)
1	44903	0	275001	197894
2	6993	0	14795	8226
3	8627	0	53854	20135
4	18466	0	203375	146872
5	1113	0	4442	1744
6	No Record	0	17008	8870
7	7359	0	41980	20424
8	37274	0	91140	39179
9	1560	0	3703	1389
10	23282	0	22176	14704
11	22515	0	32571	11604
12	48254	0	87833	56004
13	20000	0	20504	17875
14	35592	0	180714	137628
15	485 DET 1	485 DET 1	123475	39145
16	No Record	No Record	31205	27838
17	0	0	34200	30298
18	5043	0	19450	8006
19	0	0	10593	8490
20	No Record	No Record	38519	19947
21	No Record	No Record	34829	23290
22	33033	0	131358	76708
23	73470	400	113661	66306
24	No Record	No Record	29920	24920
25	No Record	No Record	61767	57289
26	36044		96373	37326
27			11441	3474
28			51178	48983
29	5500		13172	8574
30			81000	16300

	Base Allied Support Costs	MCP Support Costs	Equip Costs	O&M, Rentals, Special Tools	Pass Thru Costs	Base Year $ (1992)
1			0	0	320823	312815
2		0	0	0	22875	22037
3			0	0	62481	60921
4		0	0	0	221841	216303
5		0	0	0	5555	5351
6		0	0	0	17008	.
7	0	0	0	0	50294	49038
8		0	0	0	129295	126067
9	0	0	0	0	5603	5463
10	0	0	0	0	46658	45493
11	0	0	0	0	55686	55686
12	0	0	0	0	136087	132690
13		0	0	0	45537	43870
14		0	0	0	218364	212913
15	0	0	0	0	123475	120393
16	0	0	0	0	31205	31205
17		0	0	0	34200	33346
18			0	0	25248	24617
19		0	0	0	10593	10328
20	0	0	0	0	38519	.
21	0	0	0	0	34829	.
22		0	0	0	164391	160287
23			0	0	189331	182402
24			0	0	29920	.
25			0	0	61767	.
26					133317	129989
27					11441	11022
28					51178	51178
29					18672	17988
30					81000	78035

	Project Number	Base Name	Installation Start Year (FY)	Cable Type (C,F,O)
31	1768A2D0	GOODFELLOW	1993	F
32	0143A9B0	OFFUTT	1994	C
33	0247A8B0	MCCHORD	1993	C
34	1881A3D0	VANDENBERG	1994	F
35	1809A3D0	VANDENBERG	1994	F
36	1743A2D0	MARCH	1993	C
37	1553A3D0	LAUGHLIN	1993	F
38	1915A1D0	KIRTLAND	1993	C/F
39	1711A3D0	BARKSDALE	1993	C
40	1763A3D0	KIRTLAND	1993	C/F
41	1714A3D0	EIELSON	1993	C/F
42	2060A3D0	CANNON	1994	C
43	1852A1D0	KIRTLAND	1994	F
44	1650A3D0	VANDENBERG	1993	C
45	1739A3D0	BARKSDALE	1994	C
46	1756A2D0	EARECKSON	1993	C
47	1755A2D0	EARECKSON	1992	C
48	1820A2D0	EDWARDS	1994	C
49	1855A3D0	SHEPPARD	1994	C/F
50	1790A1D0	MARCH	1993	C

Implicit Price Deflators
Used to adjust pass through
costs to 1992$.

YR.	1987 base	1992 Base	Name of Range
92	121.10	1.00000	
93	124.20	1.02560	DEF9392
94-1	125.70	1.03799	DEF9492
94-2			

	Cable Pair-Miles	Fiber Strand-Miles	Cable Length (Ft) Installed in Manhole Duct System	Cable Length (Ft) Direct Bury	Total Cable Length (Ft)	Rocky Terrain (Y/N)
31	0.0	109.4	30750	0	30750	0
32	34.1	0.0	600	0	600	0
33	36.0	0.0	0	7600	7600	0
34	0.0	88.6	13000	0	13000	0
35	0.0	30.0	1900	275	2175	0
36	312.6	0.0	3530	0	3530	0
37	0.0	4.7	2042	40	2082	0
38	2023.7	50.3	6250	0	6250	0
39	59.0	0.0	1100	0	1100	0
40	2357.9	78.3	0	17000	17000	0
41	1713.7	3.0	2340	20719	23059	0
42	64.0	0.0	0	13500	13500	0
43	0.0	13.6	1365	10635	12000	0
44	0.5	0.0	100	0	100	0
45	37.9	0.0	1000	0	1000	0
46	5670.6	0.0	2575	50435	53010	0
47	2281.4	0.0	600	36940	37540	0
48	16.1	0.0	425	0	425	0
49	750.8	11.4	4405	0	4405	0
50	54.0	0.0	400	0	400	0

	Number of Terminal Locations	Number of Floor/Wall Penetrations	Number of Pairs Spliced	Total Width of Streets Crossed (Ft)
31	20	20	624	540
32	15	0	600	0
33	2	0	100	100
34	4	0	360	100
35	2	0	48	180
36	0	0	6900	0
37	3	4	48	100
38	16	6	18120	100
39	1	2	1200	45
40	4	0	14836	100
41	1	5	17007	200
42	3	2	50	80
43	2	1	18	
44	4	4	2100	
45	2	0	400	0
46	70	29	49500	1140
47	42	10	10150	950
48	6	1	500	0
49	5	0	8390	
50	1	4	400	0

	Number of New Manholes Installed	Total Number of Manholes	Number of New Handholes Installed	Total Number of Handholes	Length of Ducts Installed
31	13	65	2	2	43600
32	0	0	0	0	0
33	0	0	0	0	0
34	0	33	0	3	5240
35	0	13	0	0	400
36	0	11	0	0	0
37	4	5	0	0	4560
38	4	16	0	0	11400
39				0	
40	0	1	0	0	0
41	0	12	2	2	0
42					
43		6		0	
44		7		1	
45	0	3	0	0	210
46	0	5	0	0	6360
47	0	3	0	0	0
48	0	1	0	0	700
49		14			
50	1	2	0	0	

	Daily Per Diem Rate Paid	Engineering Man-hours	Installation Man-hours	Engineering Travel and Per Diem Cost
31	75	135	5632	
32	66	307	1096	
33	81	97	1293	
34	113	262	4836	0
35	113	437	2842	2768
36	88	296	1545	11075
37	66	191	1568	
38	94	116	5443	
39	87	37	382	0
40	94	102	2864	
41	166	107	2207	
42	66	16	488	400
43	94	84	3242	400
44	113	265	1278	0
45	83	94	1140	0
46	.	222	11866	
47	.			
48	140	90	312	0
49	72	372	1931	
50	88	15	93	

	Installation Travel and Per Diem Cost	QA Travel and Per Diem Cost	Installation Hardware / Supplies Costs	Total Cable Cost (inc. w/supplies)
31	12688		USER	PROVIDED
32	6437		10011	3864
33			5103	4408
34	53767		110301	61920
35	41433		.	7420
36	36944		15545	12135
37	5898		12792	2400
38	73927		117705	94376
39	1015		6968	3387
40	38332		77224	31480
41	25700		90694	75369
42	2500		12071	7830
43	17796		13462	810
44	5401		9367	135
45	8742	0	8827	5225
46			185981	115189
47	1400		0	0
48	0	0	3185	714
49	5819		65457	57848
50	1148		1669	672

	Base Allied Support Costs	MCP Support Costs	Equip Costs	O&M, Rentals, Special Tools	Pass Thru Costs	Base Year $ (1992)
31					48809	47590
32					16448	15846
33					5103	4975
34					164068	158063
35	0	0	0	0	.	.
36	0	0	0	0	63564	61977
37	0				18690	18223
38					191632	186848
39					7983	7783
40					115556	112671
41					116394	113488
42					14971	14423
43			0		31658	30499
44			0		14768	14399
45					17569	16926
46					185981	181338
47	0				1400	1400
48					3185	3068
49					71276	68667
50					2817	2746

Appendix D: NMS Definitions and Format

To the best of your ability reconstruct and provide project information and cost based on the parameters defined below.

Project Number: This is self explanatory.

Base Name: Name of Base where the NMS was installed.

Installation Start Year: Calendar year of installation start.

Number of Network Nodes: Total number of ***manageable*** devices attached to the network. Examples would be workstations, servers, print servers, and the like. This total should include all foreseeable additional quantities that may be installed in the near future. (+,-)

Number of NOS types: How many different NOS types will be managed on the network? (Numeric) (+,+)

How Many Different Levels of Security are Required?: If this network requires multilevel security classification, give the number of different levels required. Examples would be unclassified, Confidential or Secret systems. (Numeric) (+,0)

Configuration Management? (Y/N): In addition to re configuring the entire network or individual devices from a central location, this capability would include identification of the physical locations of all nodes on the network. (cat)

Fault Analysis? (Y/N): Does the NMS analyze the faults it detected? (cat)

Performance Analysis? (Y/N): Does the NMS analyze the performance it has measured? (cat)

Trouble Ticket? (Y/N): Does the NMS generate working order tickets for faults detected or called in? (cat)

Accounting? (Y/N): Does the NMS keep track of system usage's of all customers on the network, perhaps for the purpose of billing them later? (cat)

Number of Remote NMS(s): The number of distribution management sub-units (to relieve the load on the main NMS center). (Numeric) (+,+)

Environmental Controls Needed? (Y/N): As a result of this installation, were new and additional environmental control systems required to be installed? These would include air conditioning or heating systems. (cat)

System Redundancy Required? (Y/N): Does the system require a level of redundancy beyond that normally used? (cat)

Special Power Requirements? (Y/N) : Was special power equipment installed for the NMS equipment? Examples include UPS, or extensive (and expensive) surge protection used in the new system. (cat)

Floor / Rack Space Required? (Y/N): Is construction of additional floor or rack space required for the NMS equipment being installed? (cat)

Remote Access Required? (Y/N): Does this system require/allow a remotely located NMS station in addition to the main terminal? (cat)

Daily Per Diem Rate Paid: This is the actual per diem rate that was paid to installers while away from their home base at the installation site. This will sometimes be $0 when an installation is completed at the home base of the installation unit. (+,+)

Engineering Manhours In-House: The man-hours expended by CSC engineers to accomplish project-related workload.

Installation Manhours In-House: The man-hours expended by CSC installers to accomplish project-related workload.

Engineering Travel and Per Diem In-House: Travel expenses plus the daily per diem rate for CSC engineering teams when in TDY status to support project workload.

Installation Travel and Per Diem In-House: Travel expenses plus the daily per diem rate for CSC installation teams when in TDY status to support project workload.

Quality Assurance Travel and Per Diem: Travel expenses plus the daily per diem rate for CSC quality assurance teams when in TDY status to perform quality assurance evaluation duties related to the project.

Base Allied Support Costs: Consists of costs for the base civil engineering "support" work that a base would do in preparation of CSC's installation. Examples would be minor construction (less than $300K) and such items as purchase of telephone poles, sand, gravel, manholes, ducts, power upgrade etc.)

MCP Support Costs: Military Construction Program costs are major construction projects such as building a building, a major upgrade to a facility, and an extensive manhole and duct system costing over $300K.

Equipment Costs In-House: Purchase of major equipment items (the end items of equipment) or systems where 3080 dollars are required. In-house refers to government provided equipment, either through the supporting ALC, or other government acquisition activity where equipment is provided as part of the overall program.

Installation Hardware Supplies In-House: Hardware items such as cable, connectors, nuts , and bolts, supplied through the CSC warehouse.

Equipment & Software: Other equipment and/or software that might be required that is being furnished by the customer (i.e. computers, modems etc.) and their yearly recurring 3080 costs.

O&M, Rentals, Special Tools: Rental of special equipment (such as concrete cutters, trenchers etc.) to be used during installation or special tools that must be purchased for the O&M unit to operate and maintain the equipment, including recurring costs.

Telecommunications Connectivity: Cost of transferring/starting service to the local telephone company or long-haul vendor.

Training: Cost of initial training required for operational or maintenance personnel at the base.

Pass Through Costs: This is the sum of the previous cost categories and any costs incurred for which no category was specified. This represents the amount of expenses that were passed on to the installation customer. It is very important that all cost figures be based on actual, historical costs. All dollars placed here represent the one-time nature of E&I expenses.

NMS Data Collection Format

	Project Number	Base Name	Install Start YR	# of Network Nodes	# of NOS Types	# Security Levels
1						
2						

	Config. Mgmt?	Fault Analysis?	Perform. Analysis ?	Trouble Ticket?	Accoun ting ?	# of Remote NMS's
1						
2						

	New Env. Controls ?	System Redund Required?	Special Power?	New Floor Space Req'd?	Remote Access Req'd?
1					
2					

	Daily PerDiem Rate	Eng. Manhours	Install Manhours	Eng Travel/ PerDiem	Install Travel/ PerDiem	QA Travel/ PerDiem
1						
2						

	Base Allied Support $	MCP Support $	Equip - In House $	Install Hardware/Supplies $
1				
2				

	O&M, Rentals, Special Tools $	Telecomm. Connectivity $	Training $	Pass Through Costs $
1				
2				

APPENDIX E: USER'S GUIDE TO ACCOMPANY ITA COST MODEL

INDEX

Introduction

This user's guide is the partial result of an effort to build a series of parametric estimating equations for the Communications Systems Center, Tinker AFB, OK. The work was accomplished as a thesis by Captain John Bosworth and Captain Ron Wiechmann in partial fulfillment of the requirements for the Master's Degree in Cost Analysis at the Air Force Institute of Technology. The work was completed in August of 1994 and is titled "Using Parametric Cost Models to Estimate Engineering and Installation Costs of Selected Electronic Communications Systems.

This user's guide consists of the eight parts listed on the previous page and is written to give the model user a better appreciation of the capabilities and limitations of the model. This guide **does not** include specific information on the use of the EXCEL Workbook that is used to implement the estimating equations.

This guide is also intended for those responsible for maintenance of the model so they will be able to familiarize themselves with the processes used in development and the issues that confront them as they strive to keep the model updated.

ITA Model

The model for estimating Information Transfer Architecture (ITA) project costs consists of 7 equations. Definitions of the inputs to the equations are included near the end of this guide, followed by the data used in the analysis.

The first equation (1) estimates Engineering and Installation (E&I) Pass Through Costs (PTC) in 1992 dollars, which are then adjusted for inflation by equation (2).

$$\begin{aligned} PTC_{ITA} &= -74348.5 + 1049.32\sqrt{CableMiles} + 8656.38\sqrt{FiberMiles} \\ &+283.464\sqrt{DuctFeet} + 2.61543(Splices) + 7292.09\sqrt{PerDiem} \end{aligned} \tag{1}$$

$$PTC_{ITA}(199x) = PTC_{ITA} \times \frac{199xGDPDeflator}{1992GDPDeflator} \tag{2}$$

The "GDPDeflator" terms in Equation (2) refer to the latest values for the Implicit Gross Domestic Product (GDP) Deflator that are used in the model to adjust for the overall effects of inflation on the general price level. As of this writing (August 1994) the value of the 1992 deflator was 121.1 and for the latest available quarter of 1994, the deflator was 125.7. The 1992 deflator will remain constant until the base year is changed from the current 1987 base year. The values for the latest quarter are available in the "Survey of Current Business" published monthly by the US

Department of Commerce. The two previous equations together give an estimate of the pass through cost of an ITA project that is accomplished by CSC for another Air Force entity.

When an installation project is accomplished outside the Air Force but within the DoD, CSC is permitted to pass on the cost of civilian pay. To estimate this cost, use equation (3) to estimate the engineering hours for the project and equation (4) to convert to dollars.

$$EngHrs = \frac{15 * Terminations^{.23881} * Splices^{.18787} * TotalFt^{.18417}}{Miles^{.17529}} \quad (3)$$

$$CivPay_{ITA} = EngHrs \times CivilianLaborFactor \quad (4)$$

where the Civilian Labor Factor reflects 199x rates.

An additional fee for the cost of military pay is passed along when the installation is outside of the DoD altogether. This cost is estimated by equation (5) for installation hours and equation (6) is used to convert to dollars.

$$\begin{aligned} InstHrs &= -54.5984 + 23.4921(\sqrt{DuctFt}) \\ &+17.4077(\sqrt{BuryFt}) + .15171(Splices) \end{aligned} \quad (5)$$

$$MilPay_{ITA} = InstHrs \times MilitaryLaborFactor \quad (6)$$

where the Military Labor Factor reflects 199x rates.

The estimate for a project will be the sum of equations (2),(4)and(6). We expect that equations (4) and (6) will most often be $0 because most projects will be accomplished for other AF units. Equation (7) is the estimate of all pass through costs for a project.

$$CostEstimate_{ITA} = PTC_{ITA}(199x) + CivPay_{ITA} + MilPay_{ITA} \tag{7}$$

A more comprehensive explanation of how these coefficients were determined, and the types of transformations accomplished on the variables, is included in the section "Development of the ITA Cost Model" starting on page E-28.

Daily Use

The Parametric ITA Cost Model was developed so an engineer from the System Telecommunications Engineering Managers (STEM) office at the Communications System Center (CSC) will have a ready-made tool for rapidly producing a reasonably accurate cost estimate. Specifically, this model estimates the combined costs of travel and per diem, hardware, and cabling. The cost of civilian and military labor is added to the estimate when those charges are appropriately passed along to customers of CSC.

Most of the instructions on specific daily use of the ITA model will be provided by HQ CSC/SDCA, and the software engineers who developed the automated spreadsheet that implements the ITA equations, Lyle Mackey and Larry Jamison.

Most important for a daily user is to understand what the ITA model **will not** do. Understanding the limitations of the model will produce far more accurate estimates. In addition, it will help the engineer ask the right questions when preparing an estimate.

Limitations

This model will not estimate the cost (or Engineering and Installation man-hours) of expensive end-use equipment that is not part of the cabling project. Examples of this are such items that are normally considered part of the base switching system or some other commodity.

The ITA estimate will not include the cost of any Military Construction Programs (MCPs) that are necessary to prepare a base for installation of an ITA project. These types of costs are normally borne by the Base Civil Engineering Squadron and may need to be added to the ITA cost if such costs are of interest to the customer.

Cable projects often include a limited amount of "teardown" that must be accomplished in order to begin the installation of new cable. The ITA Cost Model allows for a limited amount of teardown work, but **does not** include the cost of removing large sections of cable from manhole and duct systems; nor does the cost estimate include the cost of removing large sections of aerial cable that is being removed and replaced by ducted cable. If a project will include more than the normal amount of such work, those costs must be estimated separately and then added to the cost estimated by the ITA Cost Model.

This model was developed based on the costs of installing **upgrades** to existing base cabling infrastructure. Therefore, it may be of limited use for extremely large ITA projects aimed at replacing a majority of the cabling at an entire base. Likewise, very small jobs tend to have small values for the input variables and could conceivably result in a **negative** cost estimate. Such an estimate is the result of a job that is outside the relevant range of the data used to build the ITA model. In such a case, another estimating approach should be chosen.

The significant indicators of ITA cost are: Cable-Pair Miles, Fiber-Strand Miles, the number of feet of cable installed in an existing duct system (Duct Feet), the total feet of cable installed (Total Feet), the number of Terminations (see definitions), Number of Splices, and the Daily Per Diem Rate at the installation location.

Although the data collection effort originally identified the number of feet of buried cable as a possible cost driver, the final model does not include a coefficient for buried cable. Only the equation for estimating Installation Man-hours found the number of feet of buried cable to be a significant indicator. This means that a project consisting solely of buried cable will not be estimated accurately.

The more accurate estimates of ITA project cost will have a majority of the physical characteristics available at the time of the estimate. A project estimate that relies on just a couple of the drivers included in the equations will tend to be less accurate and a different estimating methodology should perhaps be employed.

Maintenance

This section of the user's guide is written to provide an understanding of some of the steps necessary to ensure the model for ITA is kept up to date and will provide reasonable estimates in the future. This section is divided into two parts: 1) the first part covers maintenance actions to provide current inputs into the model; 2) the second part discusses briefly the need to periodically update the parameter estimates in the CER equations.

Inputs. Equation (1) of the ITA model was designed to develop estimates in 1992 base year dollars. This is a result of the necessity to adjust the original raw data, which covers a three year period, to 1992 base year dollars to account for the effects of inflation. With the output of equation (1) in 1992 dollars, we use equation (2) to adjust into current dollars. Both the adjustment for inflation in the original data, and the adjustment from 1992 dollars into current dollars depends on the values of the Implicit GDP Deflator for 1992 and for the relevant year's value of the GDP Deflator. Estimators should use the value of the most recent GDP Deflator in order to increase accuracy.

When this was written, the values of the GDP deflator used for adjustment were as shown in Table E.1. The values of the Implicit GDP Deflator are computed and published quarterly in The Survey of Current Business by the US Department of Commerce. The Survey can be found in most libraries and is also available by subscription.

Table E.1: GDP Deflators

Year/Qtr	Implicit GDP Deflator
1992/composite	121.1
1993/composite	124.2
1994/1st Qtr	125.7

In the April 1994 issue of the Survey, the deflators for the past 6 quarters and past 3 years were listed in Table 7.14 on page 25, under the heading "Implicit Price Deflators for Gross Domestic Product by Sector." To adjust for inflation, use the overall deflator on the first line of Table 7.14. Other potential sources of the latest deflator are the Wall Street Journal and a new computer bulletin board system (BBS) being installed by the Bureau of Labor Statistics. Information on accessing the "LABSTAT" BBS can be found by calling the LABSTAT help desk at 1-202-606-7060.

The model must be updated with Implicit Price Deflator information on a quarterly basis in order to properly account for the effects of inflation. Within a year or two, the Implicit GDP Deflator will probably be re-adjusted to

make 1992 the new base year. When the 1992 deflator value changes, the new value must be updated into the model similar to the quarterly update of the current (latest) quarter.

Another adjustment for inflation that must be made on an ongoing basis is the Daily Per Diem rate being paid at the installation location. For the purposes of recognizing the effects of installing projects in expensive areas, the sum of off-base lodging and meals was used as an indicator of the general price level in the area. While the adjustment for the overall price level is a general adjustment, this adjustment takes into account the **relative** effect of price level changes from one location to another. The base travel office at Tinker AFB has a current copy of the off-base lodging and meal rates at every base covered by DoD.

The current Daily Per Diem Rate (as defined above) must be entered into equation (1) for the base in question. We recommend that the person responsible for model maintenance contact the local travel office to get on the distribution list for per diem rate updates because the per diem rates are adjusted on an irregular basis. The easiest method of maintaining this data would be to give each person using the

model the current list of per diem rates to be used when making estimates with the model.

A final update on the input side is the requirement to update the Civilian and Military Labor Factors used in the model to estimate the cost of civilian and military pay that is sometimes passed on for a particular project. When the model was developed, the current factors for civilian and military pay were understood to be $75/hr and $70/hr, respectively.

The civilian and military labor factors are determined by CSC/FM and arrangements must be made with them to keep the factors current in the event a project estimate is made for a non-Air Force entity.

Parameter Estimates. As the data base of projects grows over time, the coefficient values used in the CERs will need to be updated to reflect changes in the underlying causal relationships. The process of accumulating the new data should be performed as each project is completed and then kept on hand until the next update. It is important that the coefficients be updated because the nature of the relationships can change over time as new installation methods are introduced and new technologies come into being.

The updating process should be accomplished by someone formally trained in statistical analysis. The techniques used to develop the original model are discussed later in this user's guide.

The question of how often to update the model's coefficients presents many problems. One possibility is to estimate new coefficients once each year. Another approach would be to update coefficients depending on the number of projects added to the data base (say, for example, every 20 projects). A third approach would call for an update each time the data base expands by 40%. Starting with the 50 projects available now, the model coefficients might be re-estimated after 20 more projects are completed.

The question of how often to update coefficients will have to be answered by the maintainers of the model depending on changes in the field procedures, exhibited accuracy, workload, and data availability.

Summary

Up to this point the User's Guide has provided an overview of the ITA model. Included in the discussion were suggestions for the daily use of the model as well as its limitations. The last section provided guidance on how to maintain and update the model as needed. In order to give a better understanding of how such models are developed, the next section discusses regression analysis.

Regression Analysis

This section provides a background on how parametric cost models are developed in general terms. This information is provided as a supplement for those users of the model who desire to understand more about the statistical tools used in parametric modeling. It is by no means a complete step-by-step process of model-building.

Historical Origins. A parametric cost model uses the basic concepts of regression analysis to develop a functional relationship between a dependent variable (Y) and one or more independent variables (X_1, X_2,...,X_n). Regression analysis can be traced back to the late 19th century when it was developed by Sir Francis Galton. Galton had studied the relation between heights of fathers and sons and noted that the heights of sons of both tall and short fathers appeared to "revert" or "regress" to the mean of the group (4:26). To him this phenomena was considered to be a regression to "mediocrity" (4:26). Based on his observations, Galton used mathematics to describe the relationship which has evolved into the regression analysis model most familiar today:

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon \quad (8)$$

As stated above, Y is the dependent variable being predicted by the regression model. The β parameters are called regression coefficients; β_0 is the Y intercept of the regression surface, $\beta_1,\ldots,\beta_n$ represent the slope of the regression line, and ε is the error term (4:33).

> The parameter β_1 indicates the change in the mean response per unit increase in X_1 when X_2 is held constant. Likewise, β_2 indicates the change in the mean response per unit increase in X_2 when X_1 is held constant. When the effect of X_1 on the mean response does not depend on the level of X_2, correspondingly the effect of X_2 does not depend on the level of X_1, the two independent variables are said to have additive effects or not to interact. Thus the first-order regression model is designed for independent variables whose effects on the mean response are additive or do not interact. The parameters β_1 and β_2 are frequently called partial regression coefficients because they reflect the partial effect of one independent variable when the other independent variable is included in the model and is held constant. (4:227-228)

Basic Concepts

"Regression Analysis" uses a formal model to measure the average amount of change in the dependent variable that is associated with unit changes in the amount of one or more independent variables (2:765). As the independent variable X changes according to some type of pattern, the dependent variable Y will tend to vary in a similar manner. Also, the data points will be distributed around the regression line when using one independent variable or the regression plane in the case of multiple regression.

Horngren suggests the following guidelines for regression analysis:

> 1) To the extent that physical relationships or engineering data are available for establishing cause-and-effect links, use them,
>
> 2) To the extent that relationships can be implicitly established via logic and knowledge of operations, use them (preferably in conjunction with guideline #3),
>
> 3) To the extent that the relationships in guideline 1 or 2 can be buttressed by an appropriate statistical analysis of data, use it. Regression analysis is often the best available check on guidelines 1 and 2. (4:766)

<u>Types of Data</u>. The values for β_0 and $\beta_1,\ldots,\beta_n$ are determined using collected data relevant to the problem at hand. The data can be either non-experimental or experimental. The data used in the ITA Cost Model was actual historical information from previous projects and is not subject to any type of environmental control as is the case with experimental data. A major limitation of such observational data is that they often do not provide adequate information about cause-and-effect relationships (4:36). This may indicate that while the data may be positively correlated, there may also be other underlying factors that are producing the end result.

Goals for Regression. Some goals for regression analysis are describing and understanding relationships; controlling and adjusting; and predicting or forecasting various outcomes based on some established functional relationship (4:30; 3:471-472). The coefficients for each of the independent variables can be used to describe and understand what factors are driving costs. By comparing estimated to actual costs an analyst might determine which, if any, variables are systematically too high or low in terms of their contribution to the actual cost (5:471).

An example of controlling cost is developing a usable statistical relation between costs and independent variables in some system which management is then able to use for the purpose of setting standards for divisions or branches within a company (4:31). By comparing actual results with results projected by the model, management can look into the production process and locate current or potential problems. Adjustments can then be made before the production process continues, thereby saving resources. Finally, if the basic description of a system or product is known, the man-hours to build it or the cost can be predicted through the use of a regression model.

At times these three categories may overlap and the distinction becomes blurred. While management may want to predict how many hours it will take to produce an item, they can also use the information gained from this "prediction" to control production. This data can be analyzed to determine why a production run took more or less time than was projected.

Limitations of Regression. While regression models can be very powerful and useful as a predictor, there are several factors that can limit the usefulness of a model. The first limitation is the assumption that the relationships will persist; that there is an ongoing, stable relationship between cost and the independent variable(s) used to estimate the cost (2:771). Since a model is constructed using historical data, there is no guarantee the relationships will hold true in the future. If the relationships do indeed hold true in the future, the analyst can expect good results. However, if the relationships change, the regression model will have to be adjusted to reflect the change.

A problem that can arise in multiple regression (using more than one independent variable) is multicollinearity. When this occurs the ability to isolate the effect on cost of a particular independent variable is limited. This occurs when two or more independent variables are highly correlated with each other; a correlation greater than .7 is a frequently used benchmark for designating a high correlation (2:777). However, in most cases, a high correlation could be expected since most of the variables are driving the same dependent variable. A solution to the problem of multicollinearity may be to omit one or more of the variables that are causing the problem.

Another problem that can limit the usefulness of a model is mis-specification. This refers to the many different potential incompatibilities between the application and the multiple regression linear model, which is the underlying basis and framework for a multiple regression analysis (5:502-503). Residual scatter plots can be run to check the data for non-linearity or outliers.

The model is limited by the variables selected to estimate or predict the dependent variable. When there is a long list of potential independent variables it is very easy to select some that are thought to be potential drivers that turn out to be insignificant to the model. On the other hand it is just as easy to omit some variables that may be the key to a successful model. If too many variables are included, the unnecessary variables will degrade the results. If necessary variables are omitted, the predictions will lose quality because helpful information is being ignored (5:502). That is why the process of choosing and limiting the number of variables is so important.

A regression model is usually deemed accurate only over a certain range of the independent variables, sometimes referred to as the relevant range. The scope is determined either by the design of the model or by the range of data used to construct the model (4:30). For example, if the data is for systems ranging from $200,000 to $800,000, the model may be reliable only inside this range. Predicting outside this range is risky because the model may not capture the underlying relationship for either simpler or more complex systems.

Four key assumptions must be met to ensure the estimated coefficients from a least-squares regression model are the best available unbiased estimators of the population parameters. Those four assumptions are: (1) linearity, (2) constant variance of residuals, (3) independence of residuals, and (4) normality of residuals (2:771-773).

The linearity assumption holds true for the relationship between the independent (X) and dependent (Y) variables in the relevant range for the population. Once the data is outside of this relevant range, the assumption may not hold true. The second assumption implies the data points will be randomly scattered about the true regression line and no patterns will develop. The assumption of independent residuals means the deviations of one of the variables are not related to that of another (2:773). The final assumption means the points are normally distributed about the true regression surface (2:773).

Construction of a Regression Model

Building a model is an arduous and, quite often, a very time consuming process. Throughout that process, the developer's goals should be to construct a model that will produce accurate results and be easily used by the estimator. In regards to the latter goal, the model should be constructed so that it can be easily managed and updated as new information becomes available. Therefore, the independent variables included in the model that drive the dependent variables should be carefully selected from the complete set of independent variables responsible for the total dependent variable. There are several things to consider when choosing which variables to include:

> 1) The extent to which a chosen variable contributes to reducing the remaining variation in Y after allowance is made for the contributions of other independent variables that have tentatively been included in the regression model,
>
> 2) The importance of the variable as a causal agent in the process under analysis,
>
> 3) The degree to which observations on the variable can be obtained more accurately, or quickly, or economically than on competing variables,
>
> 4) The degree to which the variables can be controlled. (4:29)

Variable Selection. It is important to select the independent variables included in the regression model very carefully. If too many variables are included to cover every possible area the result can be multicollinearity. As stated earlier, this occurs when two or more independent variables are highly correlated with each other; a correlation (also called Pearson or product-moment correlation) greater than .7 is a frequently used benchmark for designating a high correlation (2:777). While the parametric model's fit will increase with the addition of more variables, the significance of the individual variables may decrease and actually cause the regression model to be less accurate. On the other hand, care should be taken so that significant variables are not excluded from the model. Important, helpful information will be missing from the data set, and the predictions of Y will not be as good if a significant variable is not included (5:510).

Many times there may be more than one combination of independent variables that are used in a model. There are four criteria available to select the best regression model: 1) Economic Plausibility, 2) Goodness of Fit, 3) Significance of Independent Variables, 4) Specification Analysis (2:767).

In order for a model to satisfy criteria one, there should be a cause and effect relationship between independent and dependent variables. While correlation may be high between two factors there may be no cause and effect relationship. For example, the correlation between an NFC team winning the Super Bowl and the stock market moving higher may show a positive correlation. However, the fact that an NFC team wins the Super Bowl has no cause and effect relationship with the stock market. In this case, there is no economic plausibility.

The goodness of fit criteria is measured using the coefficient of determination (called r^2 or R^2 in the case of multiple regression). This measure indicates how much of the variation in the regression model is being explained by the independent variables.

The absolute value of the t-statistic is used to measure the significance of the independent variables. According to Horngren, the regression coefficient of each independent variable divided by its standard error(the t-score) should be "respectable"- at least 2.0 (for sample sizes of 60 or more, using a 95% confidence interval) (2:767). In any case, the significance of an independent variable depends upon the level of confidence the analyst wishes to attain.

The last criteria that must be adhered to is specification analysis. If a model is specified based on a particular relationship that later changes, then changes must be made to the regression model to reflect those changes.

Before blindly putting together a set of variables in a regression model, each variable should be analyzed to try to determine what type of information can be derived from that particular variable. Siegel suggests that variables may be prioritized using the following list:

> 1) Select the Y variable you wish to explain, understand, or predict,
>
> 2) Select the single X variable that you feel is most important in determining or explaining Y. If this is difficult, because you feel that they are all so important, imagine that you are forced to choose,
>
> 3) Select the most important remaining X variable by asking "With the first variable taken into account, which X variable will contribute the most new information toward explaining Y?"
>
> 4) Continue selecting the most important remaining X variable in this way until a prioritized list of X variables has been developed. At each stage, ask "With the X variables previously selected taken into account, which remaining X variable will contribute the most new information toward explaining Y?" (5:510)

Using the variables that are determined to be the most important, a regression model can be built. The model is run on a statistics program such as SAS and diagnostic results are produced. At this point it may become apparent that some of the variables included in the model did not perform as expected and variables that were left out may provide the missing link. It is up to the analyst to decide which, if any, variable(s) to replace. While this procedure is fairly subjective, it has two advantages: (1) when a choice is to be made between two X variables that are nearly equally good at predicting Y, the model developer will have control over the selection; (2) by carefully prioritizing the explanatory X variables, further insight into the situation is gained (5:510). Care should be taken not to search only for the best R^2. While some experimentation is allowable, the analyst should not just run model after model looking for the "best" fit.

Data Manipulations. If an independent variable being used does not interact in a linear fashion, the data can be adjusted using one of the following types of transformations: square roots, squares, reciprocals, or logarithms. By transforming one or more of the variables the data set may then display a more linear relationship (5:524). The transformation can take place on some or all of the X variables as well as the Y variable. However, to keep the process from getting too complicated, it is a good idea to use the same transformation on all variables that are measured in the same units, i.e., dollars or weight (5:525).

At times there may be an interaction between two or more variables. An interaction occurs when the sum of the parts is greater than the individual parts by themselves.

Siegel presents a good example using gunpowder, heat, and reaction. A pound of gunpowder does not do much by itself; neither does a lighted match all by itself. But put these together and they interact, causing a very strong explosion as the reaction (5:534-535). Allowing for interaction within a model can be accomplished by multiplying two variables together to create a "new" variable. The new variable created through the interaction can be tested for significance using the t-test and is included in the model if its inclusion will improve the predictive ability of the model.

At times it may be necessary to include data in a model that is not qualitative. For example, will air conditioning be needed for this project, Yes or No? In order to include this type of data an indicator (i.e. categorical) variable is used with values of 1=Yes and 0=No. The statistics program will determine a coefficient for the category as well as the relevant diagnostics that must be checked to determine if the categorical variable is significant.

Regression Analysis Summary

While the preceding review of regression analysis was brief, the intent was to introduce the main concepts necessary to understand regression analysis. If more information about the subject is desired, a good starting point is the material referenced in the bibliography of this User's Guide. With a better understanding of regression analysis, the following section detailing development of the ITA model should be easier to understand and follow.

Development of the ITA Cost Model

This section explains the step-by-step process followed to develop the ITA cost model, the interim results, and a more complete logic trail of how and why certain cost drivers were transformed to improve the statistics of the model.

Information Transfer Architecture (ITA)

The first step in the model developing process was to identify a series of potential cost drivers for which historical data could be reliably collected in sufficient quantity to allow a valid analysis. To accomplish this we combined the engineers' knowledge of the ITA system's characteristics and physical attributes along with our knowledge of cost estimating. We narrowed the initial list down to a workable level after many iterations. The possible cost drivers and definitions for ITA are presented at the end of the User's Guide.

After the definitions were agreed upon we provided CSC with a data collection format along with the definitions for each possible cost driver. While the data was being collected, discussions continued with the ITA engineers to determine the expected behavior for each of the cost drivers in the definition list. The postulated behavior for each ITA cost driver is included as the last item in each definition listed at the end of the User's Guide.

Data Collection Results. CSC tasked the 485th Electronics Installation Squadron (EIS) at Griffiss AFB, NY and the 1845th EIS at Tinker AFB, OK to collect historical data from previously installed ITA systems. The results of the ITA data collection effort are detailed in elsewhere at the end of the User's Guide, following the ITA definitions.

The collection effort yielded a total of 65 observations from the two squadrons. Of these 65, 37 were received from the 485th EIS at Griffiss AFB, NY and the remaining 28 were supplied by the 1845th EIS at Tinker AFB, OK. The size of the ITA jobs ranged from very small (100 feet of cable) to very large (53010 feet of cable). After analyzing the data, it was apparent some of the data would be unusable for various reasons which are discussed in the next few paragraphs.

The main reason observations were deleted from the set was due to a lack of sufficient data. Most of these were missing information for engineering and installation travel and per diem costs. In most cases the cost of the **engineering** travel and per diem did not reach substantial levels compared to the pass through costs. However, **installation** travel and per diem costs were often substantial. Therefore, those lines for which CSC could not provide a true picture of the actual pass through costs were deleted.

In addition to observations having no records available for some of the information, several projects completed by Air National Guard (ANG) units had no information for the cost of installation travel and per diem. In one case the 215th EIS from Everett, WA installed 630 feet of cable in Aviano, Italy for a total cost of $1364. The cost for this job was so low because travel and per diem was not included. In cases such as this, the pass through cost of the project was understated by a material amount and could not be used for analysis.

On some projects, a unit may have already had the equipment or cable on hand for a project. In that case the cost of such items was not included in the cost reported. Those projects were deleted if the cost of materials could not be supplied in some other way since it is not accurate to estimate the costs of a system when substantial parts of the project (material and cable) are not included.

On one project the unit doing the installation also conducted a significant amount of training at the same time. This added tremendously to the total hours it took to complete the project, thereby adding considerably to the installation travel and per diem and misrepresenting the number of installation hours required for a project of that size. The unit in question was unable to identify the additional travel cost or training hours, so the project was deleted from the data set.

Before any of the observations were dropped from the set, discrepancies were noted and forwarded to the 485th EIS and 1845th EIS for clarification. In many cases it was impossible to recover any more data for projects completed by ANG units. Some of the data initially provided seemed inconsistent with the majority of data. These items were flagged, investigated, and updated in the data set if the initial information proved to be incorrect.

Model Development. To estimate costs for an Information Transfer Architecture (ITA) project we used a format of three cost estimating relationships (CERs). The three CERs estimate Air Force (AF) pass through costs, civilian pay costs, and military pay costs. As noted earlier, the cost for civilian and military pay is not passed through on every project. In the case of civilian pay it is passed through on everything except Air Force projects, while military pay is only passed through on Non-DoD projects.

In the data set analyzed, all of the projects were for Air Force units so civilian and military pay expenses were not included in the pass through costs. This model develops these costs because CSC expects to need such estimates in the future as they seek to broaden their business base.

<u>AF Pass Through Cost CER</u>. As stated earlier, we exchanged notes with the engineers at the Communications Systems Center (CSC) to get a better understanding of an ITA system's characteristics. With a list of possible cost drivers and their potential behaviors, a CER was developed to estimate the pass through cost for an ITA system installed at an Air Force location. Below is the initial CER hypothesized to predict these costs:

$$\begin{aligned} \mathrm{PTC}_{\mathrm{ITA}} &= \beta_0 + \beta_1\sqrt{\mathrm{CableMiles}} + \beta_2\sqrt{\mathrm{FiberMiles}} + \beta_3\sqrt{\mathrm{DuctFt}} \\ &+ \beta_4 \mathrm{Terminals} + \beta_5 \mathrm{Splices} + \beta_6\sqrt{\mathrm{BuryFeet}} + \beta_7\sqrt{\mathrm{PerDiem}} \end{aligned} \tag{9}$$

The CER above was designed with the belief that each of these variables were key drivers of the materials, equipment, travel and per diem costs passed through on any ITA project. The square root transformation was used for some of the variables because the costs incurred by these variables, taken one at a time and all else held constant, would increase pass through costs but at a decreasing rate (+,-). In other words, if it costs $1000 to install 50 feet of cable it will obviously cost more to install 100 feet but it would probably be less than $2000. The same basic assumption holds for the other variables that used the square root transformation in this hypothesized model.

In the case of terminals and splices the behavior was predicted to be linear; the cost would increase but at a constant rate (+,0). Therefore, the time required to complete 100 splices would probably be double that for 50 splices.

After the CER was run in the Statistical Analysis System (SAS) program the results were analyzed. Table E.2 shows the results. As stated in Chapter III of the thesis, we chose a p-value $\leq .10$ as a general guideline to determine which variables were significant. The CER on the whole has a respectable F-score of 12.37 indicating the result is statistically significant. The p-value for the F-score of .0000 falls well below the set standard of .10. The R^2 for this CER is a fairly respectable .7181 indicating almost 72% of total variation is explained by the independent variables.

While this CER is significant, four of the variables are not significant contributors to the CER as specified because they are well above the p-value $\leq .10$ cut-off. The variance inflation factor (VIF) is an indication of multicollinearity in the CER. Multicollinearity occurs when independent variables are correlated among themselves

(4:296). Any value greater than 10 may indicate the presence of multicollinearity (3). In this case, significant multicollinearity is not indicated.

Table E.2: Initial Hypothesis
Dependent Variable = Pass Through Cost
R^2=.72, Adjusted R^2=.66
F-score=12.4

Predictor Variables	Coefficient β_i	t-score	p-value	Variance Inflation Factor
Intercept	-104900	-1.67	.10	
Square Root CableMiles	397.264	.42	.68	6.3
Square Root FiberMiles	9773.3	4.36	.00	1.6
Square Root Duct Feet	221.542	.94	.36	2.3
Terminals	-252.399	-.25	.81	1.9
Splices	3.47204	2.02	.05	7.9
Square Root Bury Feet	-.19348	-0.00	.99	1.3
Square Root PerDiem	11650.9	1.77	.09	1.1

After dropping the most insignificant variables from the model one at a time, the following relationship was tested:

$$PTC_{ITA} = \beta_0 + \beta_1\sqrt{CableMiles} + \beta_2\sqrt{FiberMiles} + \beta_3\sqrt{DuctFt} + \beta_4\sqrt{PerDiem} \quad (10)$$

As stated earlier, the variables included in this CER are hypothesized to increase at a decreasing rate (+,-), all else held constant. The results from the statistical output are summarized in Table E.3 and show a significant relationship (F=19.6) and a somewhat respectable R^2 of .68. All of the variables included in Equation (10) are significant and the low variance inflation factors indicate that multicollinearity is not significant.

Table E.3: Updated Hypothesis
Dependent Variable = Pass Through Cost
R^2=.68, Adjusted R^2=.64
F-score=19.6

Predictor Variables	Coefficient β_i	t-score	p-value	Variance Inflation Factor
Intercept	-110100	-1.76	.09	
Square Root CableMiles	2182.02	4.98	.00	1.3
Square Root FiberMiles	8755.47	4.27	.00	1.3
Square Root Duct Feet	346.037	1.81	.08	1.4
Square Root PerDiem	11154.7	1.71	.10	1.1

Within any model there is the possibility that some of the observations are erroneous outliers and may be driving the model to produce an incorrect estimate. The Statistical Analysis System (SAS) software provides information that can be used to identify influential outliers for the purposes of further investigation. Two of these checks are DFFITs and DFBETAs.

DFFITs are a measure provided for each observation in the data set and indicate the influence of the particular observation on the fitted value of cost. Each observation has a single DFFITs value. We considered a DFFITs value >1 as indicating the possibility of a observation being an influential outlier (5:401). The DFBETAs value is a measure of the influence that a particular observation has on the individual coefficients of the fitted regression surface. Each coefficient in the regression equation will have a DFBETA value for every observation in the data set. We considered a DFBETA value >1 to be an indicator that a particular observation had an influential effect on the estimate of a regression coefficient (5:403).

Taken together, we decided a particular observation was an influential outlier in the data set if it had a DFFITs value >1 **and** had at least 2 DFBETA values >1. Three observations met this criteria and were investigated. In two of the observations, incorrect data had been included in the original data set. These two items were changed to reflect their true values. However, the third observation (#35 in the ITA data set, at the end of the User's Guide) seemed to contain exaggerated Installation Hardware/Supplies cost. After verifying with CSC, it was determined that an excessive amount that should have been charged to Switching

Systems (a separate commodity) was included in the ITA cost. Since they were unable to determine how much of the Installation Hardware/Supplies cost should be deleted, this observation was not used in the analysis of the pass through costs.

With corrected data available, we ran the initial Pass Through Cost CER as stated in Equation (9). The results from the statistical output are summarized in Table E.4 followed by a discussion of the implications.

Table E.4: Initial Hypothesis, Data Corrected
Dependent Variable = Pass Through Cost
R^2=.84, Adjusted R^2=.81
F-score=24.9

Predictor Variables	Coefficient β_i	t-score	p-value	Variance Inflation Factor
Intercept	-72777	-1.63	.11	
Square Root CableMiles	1027.28	1.51	.14	6.4
Square Root ,FiberMiles	8146.98	5.05	.00	1.6
Square Root Duct Feet	344.108	2.04	.05	2.3
Terminals	-123.497	-0.17	.86	1.9
Splices	2.53125	2.07	.05	8.0
Square Root Bury Feet	98.9370	0.78	.44	1.3
Square Root PerDiem	6708.85	1.42	.16	1.2

Without observation #35 the statistics for this CER improve tremendously. However, as in the original statistics run of Equation (9), the p-value for the square root of bury feet and terminals remain very high. By dropping these variables, the CER reduces to:

$$\begin{aligned} PTC_{ITA} &= \beta_0 + \beta_1\sqrt{\text{CableMiles}} + \beta_2\sqrt{\text{FiberMiles}} \\ &+\beta_3\sqrt{\text{DuctFt}} + \beta_4\text{Splices} + \beta_5\sqrt{\text{PerDiem}} \end{aligned} \tag{11}$$

The coefficient estimates from Equation (11) are summarized in Table E.5 followed by a discussion.

Table E.5: Model for Pass Through Cost
Dependent Variable = Pass Through Cost
R^2=.84, Adjusted R^2=.8166
F-score=36.2

Predictor Variables	Coefficient β_i	t-score	p-value	Variance Inflation Factor
Intercept	-74348.5	-1.74	.09	
Square Root CableMiles	1049.32	1.65	.11	5.8
Square Root FiberMiles	8656.38	6.00	.00	1.4
Square Root Duct Feet	283.464	2.05	.05	1.6
Splices	2.61543	2.44	.02	6.3
Square Root PerDiem	7292.09	1.62	.11	1.1

The statistics in Table E.5 indicate this CER is very significant (F-score 36.19; p-value .0000). With the exception of the square root of cablemiles and the square root of per diem, all of the variables are very significant as well (p-values < .10). While the two above mentioned variables exceed the .10 guideline set earlier, they are very close to meeting this mark. Because we have believed all along that cablemiles and per diem are important components of cost for an ITA project we will leave them in the CER.

Therefore, the CER that will predict the Pass Through Cost of an Air Force ITA project in 1992 dollars is:

$$PTC_{ITA} = -74348.5 + 1049.32\left(\sqrt{CableMiles}\right) + 8656.38\left(\sqrt{FiberMiles}\right) + 283.464\left(\sqrt{DuctFt}\right) + 2.61543(Splices) + 7292.09\left(\sqrt{PerDiem}\right) \quad (1)$$

which are then adjusted for inflation into current dollars by the use of Equation (2).

$$PTC_{ITA}(199x) = PTC_{ITA} \times \frac{199xGDPDeflator}{1992GDPDeflator} \quad (2)$$

Civilian Pay CER. The estimate for ITA pass through costs will sometimes include civilian and military pay. Again, although the data collected had no projects for which those categories were included, as CSC seeks to broaden its business base they will likely need to estimate such costs in the future. Because the engineering workforce is overwhelmingly civilian and the installation workforce overwhelmingly military, we will use engineering hours as the estimator of civilian pay and installation hours as the estimator for military pay.

Estimating engineering hours presents some peculiar difficulties because so many of the possible drivers of engineering effort are subjective measures that would be very difficult to collect. Examples of this would be the abilities and experience level of the engineer(s) on a project. Also, two identical projects may take very different levels of engineering effort based on the amount of preparatory work that must be done to update the base blueprints as part of the project requirements.

Knowing that such data could not be objectively collected along with the other data, we were constrained to the physical characteristics of the project as possible "cost" drivers. On the other hand, any error in estimating engineering hours would only be multiplied by the current civilian labor factor of $75. This means that an estimating error of 100 hours would only mis-state civilian pay by $7500, which is not a material amount in an estimate that may total $250,000. This is especially true since the model is being developed to estimate cost in the very early stages of the project.

Those constraints in mind, we expected that the strongest indicators of engineering hours would be the number of terminals and splices in the project, the total number of miles (cable miles + fiber miles), and total feet of cable to be installed. From an engineering hours standpoint, both terminals and splices are indicators of project complexity while miles and total feet indicate the extent of a project. We expected all four of those drivers to increase at a decreasing rate (+,-) with respect to engineering hours.

We analyzed several different transformations relevant to that behavior and settled on the following multiplicative CER with the results in Table E.6:

$$\begin{aligned} \ln \mathrm{EngHrs} = \beta_0 + \beta_1 \ln \mathrm{Terms} + \beta_2 \ln \mathrm{Splices} \\ + \beta_3 \ln \mathrm{Miles} + \beta_4 \mathrm{TotalFeet} \end{aligned} \tag{12}$$

As shown by the F-score and low values of R^2, the relationship is significant, but very weak, and only 24.8% of the total variation is explained by the CER. While use of this estimating relationship over time will produce unbiased estimates, it will not prove to be a very accurate predictor on any one individual project. As stated earlier, the magnitude of the estimating error for engineering hours is such a small component of the total cost that the effect on the overall forecast is not likely to be material.

Table E.6: Model for Engineering Hours
Dependent Variable = ln(Engineering Hours)
R^2=.25, Adjusted R^2=.18
F-score=3.5

Predictor Variables	Coefficient	t-score	p-value	Variance Inflation Factor
Intercept	2.70854	2.04	0.05	
lnTerms	0.23881	1.75	0.09	1.5
lnSplices	0.18787	1.48	0.15	6.3
lnMiles	-.17529	-1.08	0.29	8.6
lnTotal FT	0.18417	1.15	0.26	3.5

From the standpoint of the entire CER, no significant outliers were discovered as in the cost CER, PTC_{ITA}. The statistics above result in the following CER for estimating engineering hours:

$$EngHrs = \frac{15 * Terminations^{.23881} * Splices^{.18787} * TotalFt^{.18417}}{Miles^{.17529}} \tag{3}$$

with the following estimate for civilian pay:

$$CivPay_{ITA} = EngHrs \times CivilianLaborFactor \tag{4}$$

where the civilian labor factor reflects 199X rates.

Given the weak relationship of the engineering hours CER, an additional method of estimating those hours would be prudent to provide a reality check. Perhaps the simplest method of doing this is to compute the mean and standard deviation of engineering hours data and use those statistics to provide a rough estimate. This method requires an experienced engineer to compare the apparent scope of a job to the database of historical jobs and then give an informed estimate.

To estimate based on the mean, we plotted a histogram of engineering hours in STATISTIX. Using all 48 observations with engineering hours data shows two wide outliers at four and six standard deviations above the mean. Both of these outliers involved very large projects (line numbers 14 and 23 in the data set). Given the size of these two projects, especially the number of miles of cable involved and the number of splices required, it is entirely reasonable that the number of engineering hours required is accurate. That these jobs are unusual in the set of fifty projects is not to say that they involved unreasonable levels of engineering effort. The histograms showing the engineering hours data with and without the two outliers are shown in Figures E.1 and E.2, respectively.

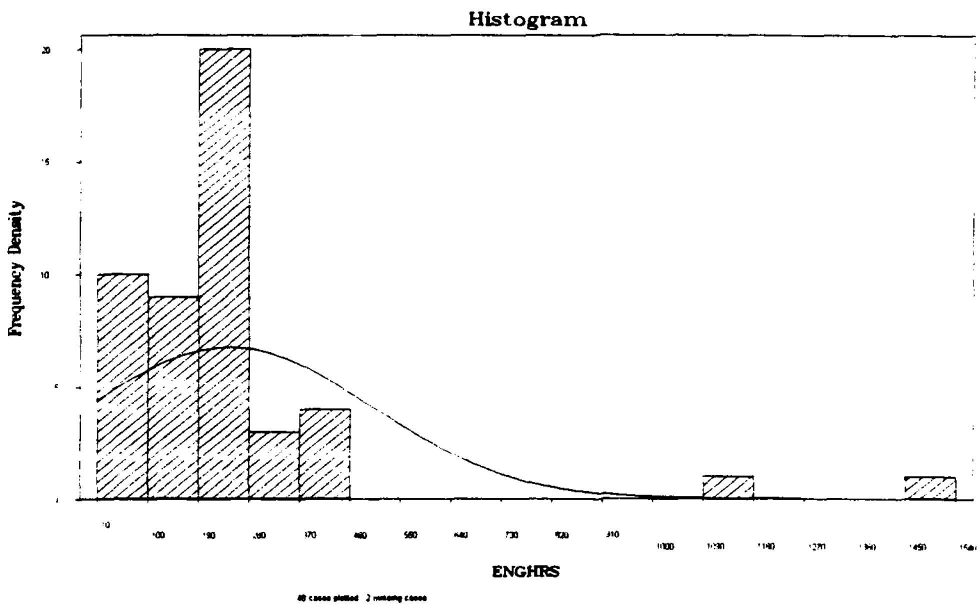

Figure E.1: Full Data Set of Engineering Hours

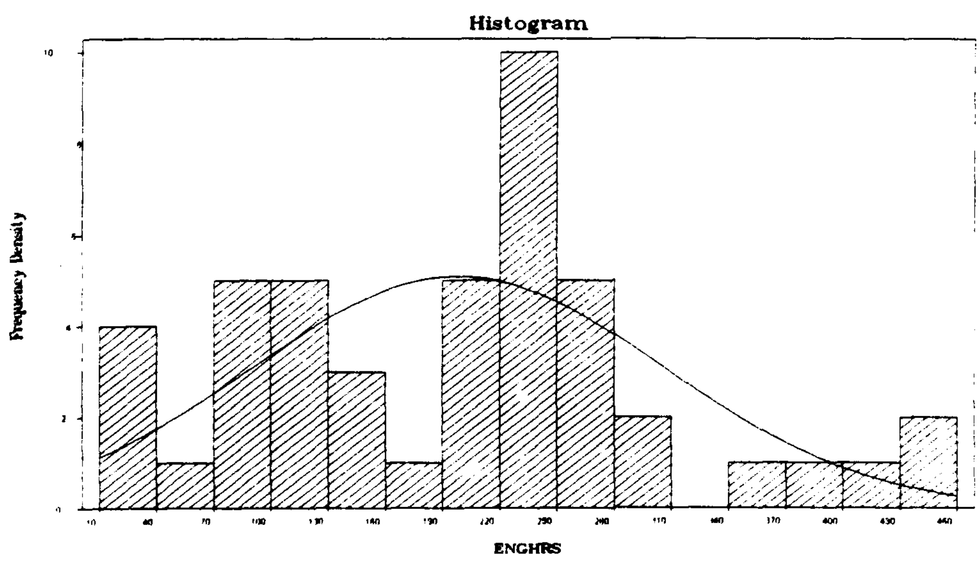

Figure E.2: Engineering Hours with Outliers Omitted

Relevant statistics on the mean and standard deviation with and without the outliers are shown in Table E.7.

Table E.7:
Descriptive Statistics
ITA Engineering Hours

Eng. Hours	All Data Points	Excluding Outliers
Mean	244.90	197.89
St. Dev.	254.76	108.24
Median	217.5	204
Min/Max	15/1531	15/454

Using this information to make an estimate requires an experienced engineer to gauge the size of a particular project and to then add or subtract a certain number of hours from the mean based on his subjective estimate of the job's complexity and the skill of the engineer(s) assigned to the task. Admittedly, this is a subjective assessment of the number of engineering hours, but it is only intended to provide a reality check to the Engineering Hours CER.

Military Pay CER. Development of the CER to predict installation hours necessary to perform a project was done in the same manner as the previous CERs discussed. The initial CER hypothesized to predict installation hours follows:

$$\begin{aligned} \text{MilPay}_{\text{ITA}} &= \beta_0 + \beta_1\sqrt{\text{Miles}} + \beta_2\sqrt{\text{DuctFeet}} \\ &+\beta_3\sqrt{\text{BuryFeet}} + \beta_4\text{Terminals} + \beta_5\text{Splices} \end{aligned} \tag{13}$$

The hypothesized CER indicates that the number of hours it would take to install an ITA is directly related to the square root of total miles of cable (cable miles + fiber miles), the square root of duct feet, the square root of buried feet, the number of terminals in a system, and finally the number of splices in the project. The first three variables in the CER are believed to increase at a decreasing rate (+,-), making the square root transformation applicable. Terminals and splices are hypothesized to increase at a constant rate (+,0), so no transformation is necessary. Table E.8 shows the results of the initial model followed by a discussion of the results.

Table E.8: Model for Installation Hours
Dependent Variable = Installation Hours
R^2=.68, Adjusted R^2.64
F-score=18.4

Predictor Variables	Coefficient	t-score	p-value	Variance Inflation Factor
Intercept	93.8501	0.15	.88	
Square Root Miles	-46.7180	-1.08	.28	7.4
Square Root Duct Feet	28.4454	3.46	.00	1.5
Square Root Bury Feet	23.4290	3.35	.00	1.7
Terminals	-50.3803	-1.50	.14	2.1
Splices	0.23254	3.58	.00	7.8

The statistics in Table E.8 indicate the variables square root of miles and terminals are not significant in this CER as their p-values are considerably greater than .10. In addition, the variables square root miles and splices have some multicollinearity between them indicating they are closely related. Since the square root of miles has such a high p-value, this variable is the likely candidate to drop out. With the miles variable dropped out of the CER the p-value of terminals gets even worse so terminals was dropped from the CER as well.

With the two variables removed from the initial hypothesized CER, another regression analysis in SAS was performed. The CER was adjusted to read as follows:

$$\text{InstHrs} = \beta_0 + \beta_1\sqrt{\text{DuctFeet}} + \beta_2\sqrt{\text{BuryFeet}} + \beta_3\text{Splice} \tag{14}$$

Using only the above three variables, the coefficients of the CER were re-computed. The results from the regression analysis are provided in Table E.9. The statistics indicate the CER is significant (F-score 29.23) and that the three variables are significant as well. While the p-value for the intercept variable is very insignificant, the intercept is outside of the relevant range of the model and is used only to provide a best fit for the regression surface.

Table E.9: Final Model for Installation Hours
Dependent Variable = Installation Hours
R^2=.66, Adjusted R^2=.64
F-score=29.2

Predictor Variables	**Coefficient**	**t-score**	**p-value**	**Variance Inflation Factor**
Intercept	-54.5984	-0.09	.93	
Square Root Duct Feet	23.4921	3.04	.00	1.3
Square Root Bury Feet	17.4077	2.92	.01	1.2
Splices	0.15171	5.61	.00	1.3

The CER to predict the installation hours needed to complete a project is:

$$\text{InstHrs} = -54.5984 + 23.4921(\sqrt{\text{DuctFeet}}) + 17.4077(\sqrt{\text{BuryFeet}}) + .15171(\text{Splices}) \tag{5}$$

with the following estimate for military pay:

$$\text{MilPay}_{\text{ITA}} = \text{InstHrs} \times \text{MilitaryLaborFactor} \tag{6}$$

where the military labor factor reflects 199X rates.

Information Transfer Architecture Model. With all three of the CERs present, the model to predict the cost of an ITA system is as follows:

$$CostEstimate_{ITA} = PTC_{ITA}(199x) + CivPay_{ITA} + MilPay_{ITA} \quad (7)$$

where $PTC_{ITA}(199x)$ is the constant dollar estimate adjusted for inflation, and $CivPay_{ITA}$ and $MilPay_{ITA}$ are understood to be in current dollars. The three CERs necessary to estimate the cost can be inserted into a spreadsheet to easily calculate the estimate for ITA.

Appendix Summary

This user's guide to the Parametric ITA Cost Model included a presentation of the Cost Estimating Relationships (CERs) used in the model, as well as sections on periodic maintenance of the model and a review of some of the techniques used to build this type of parametric model. This user's guide is a supplement to the thesis "Using Parametric Cost Models to Estimate Engineering and Installation Costs of Selected Electronic Communication Systems", published in September 1994, by the Air Force Institute of Technology.

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ITA Data Collection Definitions

Following is the list of definitions used in data collection, both in development of the models and to gather data for future projects so the models may be kept up to date. Following most definitions is a description of the type of data expected to be gathered (i.e. numeric or categorical). The equivalent definitions must be used as inputs to the model in order to estimate costs. The definitions are followed by a list of the data used to estimate the model coefficients.

Project Number: This is self explanatory.

Base Name: Name of Base where the ITA was installed.

Installation Start Year: Calendar year of installation start.

Cable Type: This refers to the predominant type of newly installed cable used for this ITA project. The types for this category are: Copper, Fiber, Other (C,F,O)

Cable Pair-Miles: This refers to the sum of {the number of cable pairs installed for each cable segment multiplied by the number of miles (ft/5280)} installed for that particular segment. (Numeric)

Fiber Strand-Miles: This refers to the sum of {the number of fiber strands installed for each cable segment multiplied by the number of miles (ft/5280)} installed for that particular segment. (Numeric)

Cable Length Installed in Manhole Duct System: This refers to the total length of cable in feet installed in the manhole duct system for this ITA project. (Numeric)

Cable Length Direct Bury: This refers to the total length of trenches (each trench can have more than one cable) in feet directly buried (to include boring) for this ITA project. (Numeric)

Total Cable Length: This refers to the total length of cable in feet installed for this ITA project; include cable in manholes, direct bury, and other.(Numeric)

Rocky Terrain: Indicates whether the ground where the ITA was installed was predominantly rocky terrain or not. (Y/N) (categorical)

Number of Terminal Locations: This refers to the number of terminals to be installed or removed for this ITA project. (Numeric)

Floor/Wall Penetrations: This refers to the number of floors/walls penetrated for this ITA project. (Numeric)

Number of Pairs Spliced: This refers to the total number of splices for each pair cable performed for this ITA project; to include the number of twisted pairs terminated. For example, termination of a 25 pair cable in a building is considered 25 splices. (Numeric)

Width of Streets Crossed: This refers to the total feet of streets crossed for this ITA project. (Numeric)

Number of New Manholes Installed: Total number of manholes installed in this project. (Numeric)

Total Number of Manholes: This refers to the total number of manholes in this project. (Numeric)

Number of New Handholes Installed: Total number of handholes installed in this project. (Numeric)

Total Number of Handholes: This refers to the total number of handholes in this project. (Numeric)

Length of New Ducts Installed: This refers to the total feet of ducting installed for this ITA project. (Numeric) (For example, 10 ducts in a 100 foot section equals 1000 feet of Ducting.)

Daily Per Diem Rate Paid: This is the actual per diem rate that was paid to installers while away from their home base at the installation site. **Computed as the sum of off-base lodging and meals,** and used as an indicator of the cost of living at the installation sites. This will sometimes be $0 when an installation is completed at the home base of the installation unit. ($)

Engineering Man-hours In-House: The man-hours expended by CSC engineers to accomplish project-related workload. (Numeric)

Installation Man-hours In-House: The man-hours expended by CSC installers to accomplish project-related workload. (Numeric)

Engineering Travel and Per Diem In-House: Travel expenses plus the daily per diem rate for CSC engineering teams when in TDY status to support project workload. ($)

Installation Travel and Per Diem In-House: Travel expenses plus the daily per diem rate for CSC installation teams when in TDY status to support project workload. ($)

Quality Assurance Travel and Per Diem: Travel expenses plus the daily per diem rate for CSC quality assurance teams when in TDY status to perform quality assurance evaluation duties related to the project. ($)

Installation Hardware Supplies In-House: Hardware items such as cable, connectors, nuts , and bolts, supplied through the CSC warehouse.

Cable Cost: This refers to the total cost of cable for this ITA project.

Base Allied Support Costs: Consists of costs for the base civil engineering "support" work that a base would do in preparation of CSC's installation. Examples would be minor construction (less than $300K) and such items as purchase of telephone poles, sand, gravel, manholes, ducts, power upgrade, etc.

MCP Support Costs: Military Construction Program costs are major construction projects such as building a building, a major upgrade to a facility, and an extensive manhole and duct system costing over $300K.

Equipment Costs: Purchase of major equipment items (the end items of equipment) or systems. This includes government provided equipment, either through the supporting ALC, or other government acquisition activity where equipment is provided as part of the overall program or equipment provided by the contractor.

O&M, Rentals, Special Tools: Rental of special equipment (such as concrete cutters, trenchers etc.) to be used during installation or special tools that must be purchased for the O&M unit to operate and maintain the equipment.

Pass Through Costs: This is the sum of the previous cost categories and any costs incurred for which no category was specified. This represents the amount of expenses that were passed on to the installation customer. It is very important that all cost figures be based on actual, historical costs. All dollars placed here represent the one-time nature of E&I expenses.

ITA DATA

	Project Number	Base Name	Install. Start Year (FY)	Cable Type (C,F,O)
1	0175A2B0	Antigua AFS	1993	C,F
2	0044A2B0	Tyndall AFB	1994	F
3	0282A2B0	Tyndall AFB	1993	C
4	0280A2B0	Tyndall AFB	1993	F
5	0835A3B0	Langley AFB	1994	C
6	0013A0L0	Bitburg AB	1993	C
7	0576A3B0	Maxwell AFB	1993	C
8	0651A3B0	Langley AFB	1993	F
9	0699A3B0	Maxwell AFB	1993	F
10	0893A3B0	Cape Canaveral	1993	F
11	1763A0D0	Cape Canaveral	1992	C,F
12	1925A9D0	Tyndall AFB	1993	C
13	2030A3B0	Fairchild	1994	C
14	2181A4D0	Langley AFB	1993	C
15	0144A1B0	Einsiedlerhof	1993	C,F
16	0180A2B0	Langley AFB	1992	F
17	0239A0B0	Griffiss AFB	1993	C
18	0306A2B0	Maxwell AFB	1993	C,F
19	0402A7B0	Griffiss AFB	1993	C
20	0037A2B0	Gunter AFB	1993	F
21	0250A2B0	Cape Canaveral	1992	F
22	1900A8D0	Langley AFB	1993	C
23	0107A1B0	Toledo ANGB, OH	1994	C
24	0350A0B0	Wright-Patt AFB, OH	1992	F
25	0448A3B0	KI Sawyer	1993	C
26	1745A2D0	MARCH	1993	C
27	1965A3D0	VANDENBERG	1994	C
28	1719A6D0	LACKLAND	1992	C
29	1526A3D0	EDWARDS	1994	C
30	1803A3D0	NELLIS	1994	C

ITA DATA

	Cable Pair-Miles	Fiber Strand-Miles	Cable Length (Ft) Installed in Manhole Duct System	Cable Length (Ft) Direct Bury
1	3368.0	60.0	35958	0
2	0.0	17.0	2802	1200
3	420.5	0.0	11485	0
4	0.0	314.0	2000	14666
5	31.5	0.0	0	1400
6	189.5	0.0	0	7050
7	545.5	0.0	1200	0
8	0.0	81.0	17445	13723
9	0.0	2.4	2099	0
10	0.0	18.4	8540	1500
11	298.0	3.0	4591	0
12	1719.7	0.0	5289	2175
13	28.4	0.0	3500	9000
14	3990.0	0.0	14125	9800
15	486.7	19.0	6980	0
16	0.0	43.0	7572	0
17	717.6	0.0	200	4730
18	42.6	14.0	3834	0
19	31.7	0.0	200	2800
20	0.0	28.8	6200	530
21	0.0	43.9	5700	1500
22	2435.6	0.0	6825	1450
23	1122.0	0.0	12260	8165
24	0.0	15.0	3258	0
25	649.0	0.0	1170	32670
26	2323.0	0.0	8309	765
27	41.0	0.0	700	600
28	872.0	0.0	7645	520
29	167.0	0.0	250	1850
30	683.0	0.0	4500	0

ITA DATA

	Total Cable Length (Ft)	Rocky Terrain (Y/N)	Number of Terminal Locations	Number of Floor/Wall Penetrations
1	35958	1	8	2
2	4002	0	2	0
3	11485	0	17	17
4	16666	0	5	0
5	1400	0	2	1
6	7050	0	15	3
7	1200	0	2	0
8	31168	0	26	11
9	2099	0	2	0
10	10040	1	9	0
11	4591	1	3	0
12	7464	0	5	0
13	12500	0	2	0
14	23925	0	16	0
15	6980	0	8	0
16	7572	0	3	0
17	4930	0	2	0
18	3834	0	4	0
19	3000	0	2	1
20	6730	0	5	0
21	7200	0	15	0
22	8275	0	12	4
23	20425	0	35	6
24	3258	0	5	0
25	34440	0	11	11
26	9074	0	46	14
27	1300	0	8	0
28	8165	0	2	0
29	2200	0	1	2
30	4500	0	9	0

ITA DATA

	Number of Pairs Spliced	Total Width of Streets Crossed (Ft)	Number of New Manholes Installed	Total Number of Manholes
1	24150	0	35	56
2	60	30	0	4
3	6456	0	13	13
4	426	270	0	7
5	600	10	0	0
6	1706	20	0	0
7	14400	0	0	3
8	168	300	0	4
9	48	0	0	2
10	38	0	0	12
11	3320	0	0	9
12	23450	0	0	31
13	60	30	0	11
14	40348	200	0	30
15	19900	0	0	11
16	90	0	0	17
17	6400	60	0	3
18	1406	0	2	4
19	600	40	0	1
20	204	0	0	5
21	348	0	0	13
22	42350	300	0	26
23	29928	2695	17	17
24	102	220	0	8
25	1238	1770	0	9
26	32800	700	9	14
27	650	0	0	3
28	8425	160	2	26
29	1600	185	0	1
30	11700	0	0	19

ITA DATA

	Number of New Handholes Installed	Total Number of Handholes	Length of Ducts Installed	Per Diem Rate Paid
1	0	0	80000	151
2	0	0	0	79
3	0	0	35000	74
4	0	0	0	74
5	0	0	0	117
6	0	0	0	102
7	0	0	0	74
8	3	7	2000	113
9	0	0	0	74
10	0	0	0	93
11	0	0	0	93
12	0	4	0	74
13	0	0	0	85
14	0	0	0	113
15	0	2	0	.
16	0	0	0	111
17	0	0	0	90
18	0	0	6200	74
19	0	0	0	90
20	0	0	0	77
21	0	0	0	93
22	0	0	1548	113
23	11	11	32420	86
24	0	0	0	93
25	0	5	0	68
26	4	4	21594	88
27	0	0	0	113
28	0	0	5900	87
29	0	0	0	140
30	0	0	0	107

ITA DATA

	Engineering Man-hours	Installation Man-hours	Engineering Travel and Per Diem Cost	Installation Travel and Per Diem Cost
1	275	3926	919	44903
2	237	1730	1087	6993
3	121	1995	0	8627
4	247	7019	0	18466
5	140	56	0	1113
6	260	4480	No Record	No Record
7	222	1712	955	7359
8	358	6493	881	37274
9	35	490	340	1560
10	168	1426	1200	23282
11	49	1376	600	22515
12	Contract	10356	Contract	48254
13	271	2632	5033	20000
14	1531	17095	2058	35592
15	454	3747	485 DET 1	485 DET 1
16	195	2416	No Record	No Record
17	410	2844	0	0
18	191	2400	755	5043
19	194	830	0	0
20	244	2123	No Record	No Record
21	235	1858	No Record	No Record
22	123	12195	No Record	33033
23	1121	5126	1800	73470
24	100	1008	No Record	No Record
25	239	2812	No Record	No Record
26	243	3401	900	36044
27	235	988		
28	155	3957		
29	213	1118		5500
30	244	3528		

ITA DATA

	QA Travel and Per Diem Cost	Installation Hardware / Supplies Costs	Total Cable Cost (inc. w/supplies)	Base Allied Support Costs
1	0	275001	197894	
2	0	14795	8226	
3	0	53854	20135	
4	0	203375	146872	
5	0	4442	1744	
6	0	17008	8870	
7	0	41980	20424	0
8	0	91140	39179	
9	0	3703	1389	0
10	0	22176	14704	0
11	0	32571	11604	0
12	0	87833	56004	0
13	0	20504	17875	
14	0	180714	137628	
15	485 DET 1	123475	39145	0
16	No Record	31205	27838	0
17	0	34200	30298	
18	0	19450	8006	
19	0	10593	8490	
20	No Record	38519	19947	0
21	No Record	34829	23290	0
22	0	131358	76708	
23	400	113661	66306	
24	No Record	29920	24920	
25	No Record	61767	57289	
26		96373	37326	
27		11441	3474	
28		51178	48983	
29		13172	8574	
30		81000	16300	

ITA DATA

	MCP Support Costs	Equip Costs	O&M, Rentals, Special Tools	Pass Thru Costs	Base Year $ (1992)
1		0	0	320823	312815
2	0	0	0	22875	22037
3		0	0	62481	60921
4	0	0	0	221841	216303
5	0	0	0	5555	5351
6	0	0	0	.	.
7	0	0	0	50294	49038
8	0	0	0	129295	126067
9	0	0	0	5603	5463
10	0	0	0	46658	45493
11	0	0	0	55686	55686
12	0	0	0	136087	132690
13	0	0	0	45537	43870
14	0	0	0	218364	212913
15	0	0	0	123475	120393
16	0	0	0	31205	31205
17	0	0	0	34200	33346
18		0	0	25248	24617
19	0	0	0	10593	10328
20	0	0	0	.	.
21	0	0	0	.	.
22	0	0	0	164391	160287
23		0	0	189331	182402
24		0	0	.	.
25		0	0	.	.
26				133317	129989
27				94796	91326
28				75373	75373
29				18287	17617
30				81000	78035

ITA DATA

	Project Number	Base Name	Install. Start Year (FY)	Cable Type (C,F,O)
31	1768A2D0	GOODFELLOW	1993	F
32	0143A9B0	OFFUTT	1994	C
33	0247A8B0	MCCHORD	1993	C
34	1881A3D0	VANDENBERG	1994	F
35	1809A3D0	VANDENBERG	1994	F
36	1743A2D0	MARCH	1993	C
37	1553A3D0	LAUGHLIN	1993	F
38	1915A1D0	KIRTLAND	1993	C/F
39	1711A3D0	BARKSDALE	1993	C
40	1763A3D0	KIRTLAND	1993	C/F
41	1714A3D0	EIELSON	1993	C/F
42	2060A3D0	CANNON	1994	C
43	1852A1D0	KIRTLAND	1994	F
44	1650A3D0	VANDENBERG	1993	C
45	1739A3D0	BARKSDALE	1994	C
46	1756A2D0	EARECKSON	1993	C
47	1755A2D0	EARECKSON	1992	C
48	1820A2D0	EDWARDS	1994	C
49	1855A3D0	SHEPPARD	1994	C/F
50	1790A1D0	MARCH	1993	C
		Implicit Price Deflators		
		Used to adjust pass through		
		costs to 1992$.		
				Name of Range
	YR.	1987 base	1992 Base	
	92	121.10	1.00000	
	93	124.20	1.02560	DEF9392
	94-1	125.70	1.03799	DEF9492
	94-2			

ITA DATA

	Cable Pair-Miles	Fiber Strand-Miles	Cable Length (Ft) Installed in Manhole Duct System	Cable Length (Ft) Direct Bury
31	0.0	109.4	30750	0
32	34.1	0.0	600	0
33	36.0	0.0	0	7600
34	0.0	88.6	13000	0
35	0.0	30.0	1900	275
36	312.6	0.0	3530	0
37	0.0	4.7	2042	40
38	2023.7	50.3	6250	0
39	59.0	0.0	1100	0
40	2357.9	78.3	0	17000
41	1713.7	3.0	2340	20719
42	64.0	0.0	0	13500
43	0.0	13.6	1365	10635
44	0.5	0.0	100	0
45	37.9	0.0	1000	0
46	5670.6	0.0	2575	50435
47	2281.4	0.0	600	36940
48	16.1	0.0	425	0
49	750.8	11.4	4405	0
50	54.0	0.0	400	0

ITA DATA

	Total Cable Length (Ft)	Rocky Terrain (Y/N)	Number of Terminal Locations	Number of Floor/Wall Penetrations
31	30750	0	20	20
32	600	0	15	0
33	7600	0	2	0
34	13000	0	4	0
35	2175	0	2	0
36	3530	0	0	0
37	2082	0	3	4
38	6250	0	16	6
39	1100	0	1	2
40	17000	0	4	0
41	23059	0	1	5
42	13500	0	3	2
43	12000	0	2	1
44	100	0	4	4
45	1000	0	2	0
46	53010	0	70	29
47	37540	0	42	10
48	425	0	6	1
49	4405	0	5	0
50	400	0	1	4

ITA DATA

	Number of Pairs Spliced	Total Width of Streets Crossed (Ft)	Number of New Manholes Installed	Total Number of Manholes
31	624	540	13	65
32	600	0	0	0
33	100	100	0	0
34	360	100	0	33
35	48	180	0	13
36	6900	0	0	11
37	48	100	4	5
38	18120	100	4	16
39	1200	45		
40	14836	100	0	1
41	17007	200	0	12
42	50	80		
43	18			6
44	2100			7
45	400	0	0	3
46	49500	1140	0	5
47	10150	950	0	3
48	500	0	0	1
49	8390			14
50	400	0	1	2

ITA DATA

	Number of New Handholes Installed	Total Number of Handholes	Length of Ducts Installed	Per Diem Rate Paid
31	2	2	43600	75
32	0	0	0	66
33	0	0	0	81
34	0	3	5240	113
35	0	0	400	113
36	0	0	0	88
37	0	0	4560	66
38	0	0	11400	94
39		0		87
40	0	0	0	94
41	2	2	0	166
42				66
43		0		94
44		1		113
45	0	0	210	83
46	0	0	6360	.
47	0	0	0	.
48	0	0	700	140
49				72
50	0	0		88

ITA DATA

	Engineering Man-hours	Installation Man-hours	Engineering Travel and Per Diem Cost	Installation Travel and Per Diem Cost
31	135	5632		12688
32	307	1096		6437
33	97	1293		
34	262	4836	0	53767
35	437	2842	2768	41433
36	296	1545	11075	36944
37	191	1568		5898
38	116	5443		73927
39	37	382	0	1015
40	102	2864		38332
41	107	2207		25700
42	16	488	400	2500
43	84	3242	400	17796
44	265	1278	0	5401
45	94	1140	0	8742
46	222	11866		
47				1400
48	90	312	0	0
49	372	1931		5819
50	15	93		1148

ITA DATA

	QA Travel and Per Diem Cost	Installation Hardware / Supplies Costs	Total Cable Cost (inc. w/supplies)	Base Allied Support Costs
31		USER	PROVIDED	
32		10011	3864	
33		5103	4408	
34		110301	61920	
35		.	7420	0
36		15545	12135	0
37		12792	2400	0
38		117705	94376	
39		6968	3387	
40		77224	31480	
41		90694	75369	
42		12071	7830	
43		13462	810	
44		9367	135	
45	0	8827	5225	
46		185981	115189	
47		0	0	0
48	0	3185	714	
49		65457	57848	
50		1669	672	

ITA DATA

	MCP Support Costs	Equip Costs	O&M, Rentals, Special Tools	Pass Thru Costs	Base Year $ (1992)
31				48809	47590
32				17962	17304
33				6875	6703
34				164068	158063
35	0	0	0	.	.
36	0	0	0	63564	61977
37				24104	23502
38				193000	188182
39				7983	7783
40				115556	112671
41				116900	113982
42				14971	14423
43		0		31658	30499
44		0		14768	14399
45				17569	16926
46				421641	411116
47				190120	190120
48				3185	3068
49				71276	68667
50				4361	4252

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Vita

Captain John Bosworth was born on 11 May 1960 in Havre, Montana. He graduated from Yucca Valley High School (California), in 1978 and entered the United States Coast Guard, where he was trained as an avionics technician and accumulated nearly 1100 hours as a navigator on HC-130H aircraft. Upon release from active duty in 1984, he attended American River College and earned a Bachelor of Science with honors in Business Administration (Accountancy) from California State University, Sacramento in 1988. He completed Officer Training School in August 1989 and after completing training as an Air Weapons Controller in March of 1990 was assigned to the Northwest Air Defense Sector at McChord AFB near Tacoma, WA. He entered the Graduate School of Logistics and Acquisition Management of the Air Force Institute of Technology as a Cost Analysis major in June of 1992. Captain Bosworth is married to the former Rhonda D. Carlisle and they have two children; George and Jonathan.

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Vita

Captain Ron Wiechmann was born on 1 June 1960 in Sauk Centre, Minnesota. He graduated from Belgrade High School (Minnesota), in 1978. In 1982 he enlisted in the Air Force and served as a Korean voice processing technician at Osan AB, Korea and Fort Meade, Maryland. Captain Wiechmann earned a Bachelor of Science Degree in Business Management/Accounting from the University of Maryland in 1988. He completed Officer Training School in December 1989 and after completing Undergraduate Missile Training in March 1990 was assigned to the 44th Missile Wing at Ellsworth AFB near Rapid City, South Dakota as a Missile Combat Crewmember. He entered the Graduate School of Logistics and Acquisition Management of the Air Force Institute of Technology as a Cost Analysis major in June of 1992. He completed a Masters of Business Administration from the University of South Dakota in August of 1994. Captain Wiechmann and his wife Kim have two children; Benjamin and Sabrina.

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13. ABSTRACT *(Maximum 200 words)*

This study developed a set of cost driver definitions for use by the Communications Systems Center (CSC), headquartered at Tinker AFB, Oklahoma. CSC is responsible for the engineering and installation of a dozen types of ground-based electronic communication and navigation systems, ranging from mobile radio systems to base telephone switches and air traffic control systems. Under changes brought about by the implementation of the Defense Business Operating Fund (DBOF), the Communications System Center is searching out new customers and new cost estimating methodologies to improve customer service. The definitions were used to gather historical data of equipment, engineering, and installation costs of Local Area Networks, Information Transfer Architecture (ITA), and Network Management Systems. From the gathered data, the researchers were able to construct a Cost Estimating Relationship for predicting the costs of an ITA project that are passed through to CSC customers. This ITA model will be used by CSC to estimate pass through costs early in the bidding process.

14. SUBJECT TERMS

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